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A Microplankton Survey as a Contribution to the Hydrography of the North Pacific and Adjacent Seas (I)

—Distribution of the microplankton and their relation to the character of water masses and currents in the North Pacific Ocean in the summer of 1957—

By

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(Received January 11, 1963)

1. *Introduction*

It is now an established oceanographic concept that there exists a current system in the North Pacific Ocean as is shown in Fig. 1 (SVERDRUP et al., 1942). Recently international cooperative observations such as the NORPAC expeditions in 1955 and IGY observations in 1957–1958 were made, and the general features of physical, chemical and biological conditions have been fairly well clarified. But it is not so easy to grasp an outline of the distribution of microplankton in the entire North Pacific Ocean even in the cases of the two above international observations, because of non-existence of any internationally standardized method for the description of microplankton. Fortunately the authors got microplankton samples from the area 20°—40°N in the North Pacific Ocean as is shown in Fig. 2, though no other information except water temperature (Fig. 3) was obtained. In this present paper, characters of those above mentioned currents are shown obviously to be connected with the distribution of surface microplankton, and it is recognized that there is a discontinuity of microplankton associations in both population and composition in the high seas around 35° N in the North Pacific Ocean.

Plankton samples were collected on board the "Nihon Maru" and "Kaiō Maru" of the Navigation Training Establishment on their training voyages Tokyo—Seattle and Tokyo—Los Angeles respectively via Honolulu. Sampling methods were the same as MARUMO (1955) adopted in this area. Namely 330 cc surface water was drawn up with a bucket. This water was reduced to about

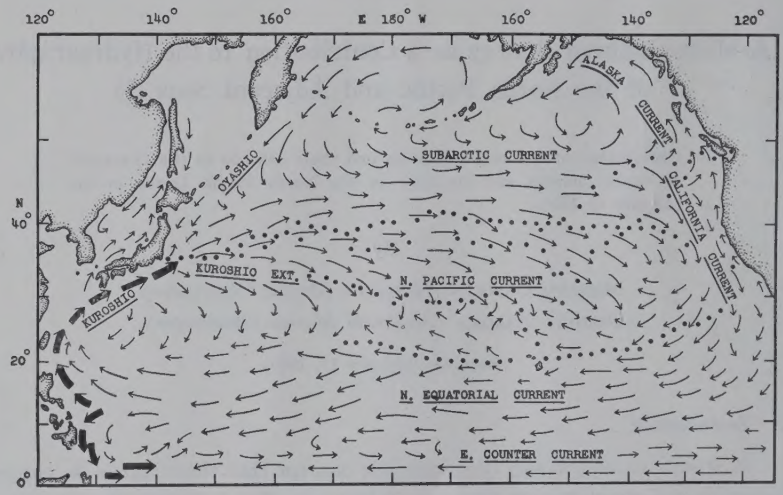

Fig. 1. Surface currents of the North Pacific Ocean (after SVERDRUP et al.).

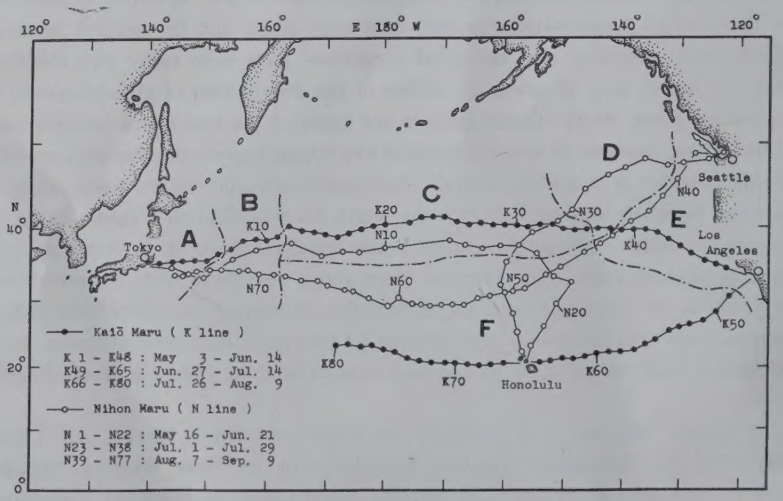

Fig. 2. Observation stations (the numerals on the observational lines denote station numbers), and demarcation of regions (A-F) which are set according to the characteristics of diatom communities.

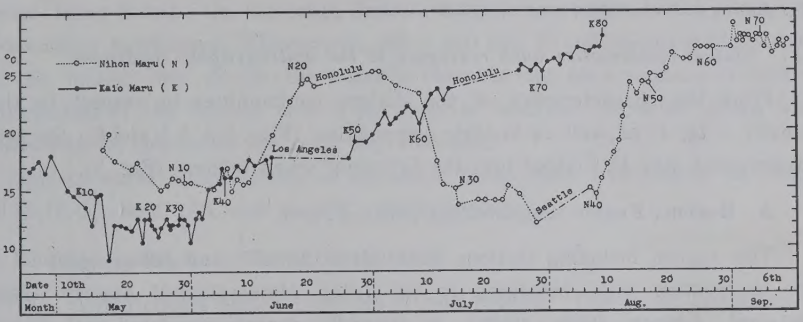

Fig. 3. Distribution of surface water temperature. The numerals on each line mean station numbers.

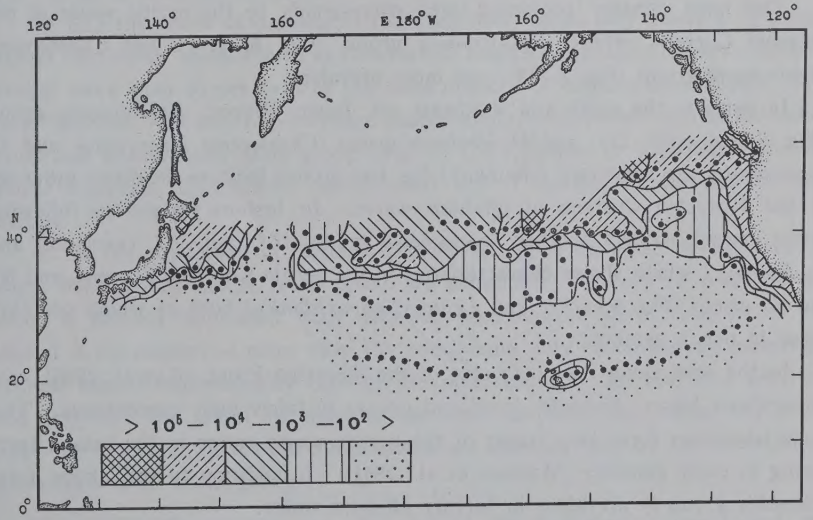

Fig. 4. Distribution of number of diatom cells in one liter of surface sea water.

15 cc by decanting with a siphon and the 15 cc water was again reduced to several drops with a centrifuge. Plankton organisms in these drops were identified and counted under a microscope. In this paper the "cell number" shows that of microplankton in one liter of surface sea water.

2. Biological characters of surface waters

(1) Diatom communities with reference to the hydrographic conditions

From the characteristics of the diatom communities in respect to their density (Fig. 4) as well as to their composition (Figs. 5-a, 5-b and 6), the areas investigated may be divided into the following seven regions (Fig. 2).

A Region; Region neighbouring Japan Proper

This region, including stations K1-6, N1-2, N75-77, and those occupied by the observation ships belonging to the Japan Meteorological Agency (Japan Meteorol. Agency, 1958a, 1958b), is generally densely populated with diatoms which are present to the maximum number of more than 10^5 cells per one liter of water near the southeast coast of Hokkaido. Surface water temperature ranges from 27° to 7°C at the stations from south to north.

The most densely populated area corresponds to the neritic water of the Oyashio Current, where *Thalassiosira* group (Fig. 6, (19)) and *Chaetoceros-Hyalochaete* group (Fig. 6, (3)) are most prevalent.

In parts to the south and southeast off Japan Proper, *Rhizosolenia* group (Fig. 6, (16) and (17)) and *Hyalochaete* group (*Chaetoceros lorenzianus* and *C. messanensis*) are relatively dominant; the two groups indicate the direct influence of the Kuroshio Current in offshore water. In inshore waters the following forms prevail, namely another *Hyalochaete* group (*C. affinis*, *C. curvisetus* and *C. didymus*) which shows characteristics of the neritic Kuroshio Current, and *Nitzschia* group (Fig. 6, (13)) and *Leptocylindrus danicus* both of which ordinary occur in neritic waters.

In the area along the north side of the Kuroshio Front (Kawai, 1955) east of northern Japan, *Eucampia zoodiacus* occurs in fairly high percentages. This is an important form as a tracer of the neritic warm water in the season from spring to early summer (Marumo et al., 1961). In addition to the above form *Nitzschia* group is prevalent in further offshore water.

B Region; Region of Kuroshio Extention

In this region covering Sts. K 7-11, N 3-5 and N 69-74 the total population of diatoms is very small, less than 10^2 cells per liter. The leading forms on the north line (K 7-11) are *Asteromphalus heptactis*, *Chaetoceros concavicornis* and *Coscinodiscus stellaris* Rop. which belong to cold-water species, no warm-water

species being found. On the south line (N 69-74) warm-water forms including *Climacodium biconcavum*, *Rhizosolenia calcar avis* and *R. styliformis* predominate. On the middle line (N3–5) the water is characterized by a mixture of diatom communities of the former two lines while in addition *Nitzschia* group and *Thalassiothrix longissima* are relatively abundant.

Surface water temperatures on the above three lines from north to south are 12–15°C, about 17°C and 26–28°C, respectively.

C Region; Region of Subarctic Current

This region covers Sts. K12–36, N6–17 and N28–29. The water temperature is relatively low with fluctuation from 9.0 to 12.8°C, showing the lowest 9.0°C at K12 on the K line. On the N line it becomes higher, fluctuating from 15.0 to 17.0°C. The amount of total diatoms is generally large ranging from about $4 \cdot 10^2$ to $14 \cdot 10^4$ cells to the liter.

At K12 the count of diatoms is relatively low, being only about $4 \cdot 10^2$ cells; typical cold-water species such as *Chaetoceros concavicornis* and *Corethron hystrix* occupy more than 40 per cent of the total number of diatoms respectively. The water between K13 and K36 contains mainly ubiquitous species such as *Nitzschia* group and *Rhizosolenia alata* group (Fig. 6, (14)), while in addition, *Asteromphalus heptactis*, *Chaetoceros concavicornis* and *Tropidoneis antarctica* are also present.

At N6 the population of diatoms is moderate, showing about $34 \cdot 10^2$ cells in which *Nitz.* group and *R. alata* group are dominant. Between N7 and N13 the water is densely populated with diatoms, especially at N8–10, where they are present to the number of more than 10^4, comprising only *Coscinodiscus curvatulus* Grunow almost monotonously through all these stations. In the area between N14 and N17 the count of diatoms becomes relatively low, being only about $3 \cdot 10^3$—10^2 cells, and the diatom communities are characterized by the monotonous appearence of *R. alata* group.

D Region; Region between the end of the Subarctic Current and the southeastern part of the Gulf of Alaska

This region covers Sts. K37–38 and N30–35, where the water temperature is 13.5–15.5°C. The water is populated with diatoms in considerable density. The predominant species are *R. alata* group, *Nitz.* group and *Coscinodiscus* group showing a close resemblance with those of the K line in the C region.

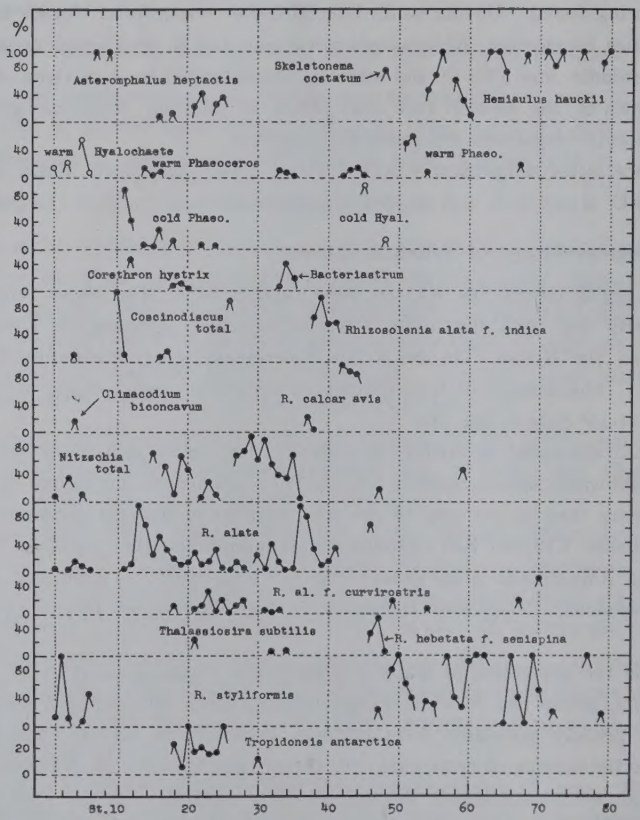

Fig. 5–a. Percentages of the cell number of important species to the total diatom cells (sampled on board the Kaiō Maru).

warm *Phaeoceros*: *Chaetoceros atlanticus* v. *neapolitana* (Schröder) Hustedt, *C. dadayi* Pavillard, *C. danicus* Cleve.

cold *Phaeo.*: *C. atlanticus* Cleve, *C. concavicornis* Mangin.

warm *Hyalochaete*: *C. affinis* Lauder, *C. curvisetus* Cleve, *C. didymus* Ehrenberg, *C. lorenzianus* Grunow, *C. messanensis* Castracane.

cold *Hyal.*: *C. compressus* Lauder, *C. constrictus* Gran, *C. debilis* Cleve.

Coscinodiscus total: *C. excentricus* Ehrenberg, *C. radiatus* Ehrenberg, *C. stellaris* Roper, *C.* spp.

Nitzschia total: *N. delicatissima* Cleve, *N. seriata* Cleve.

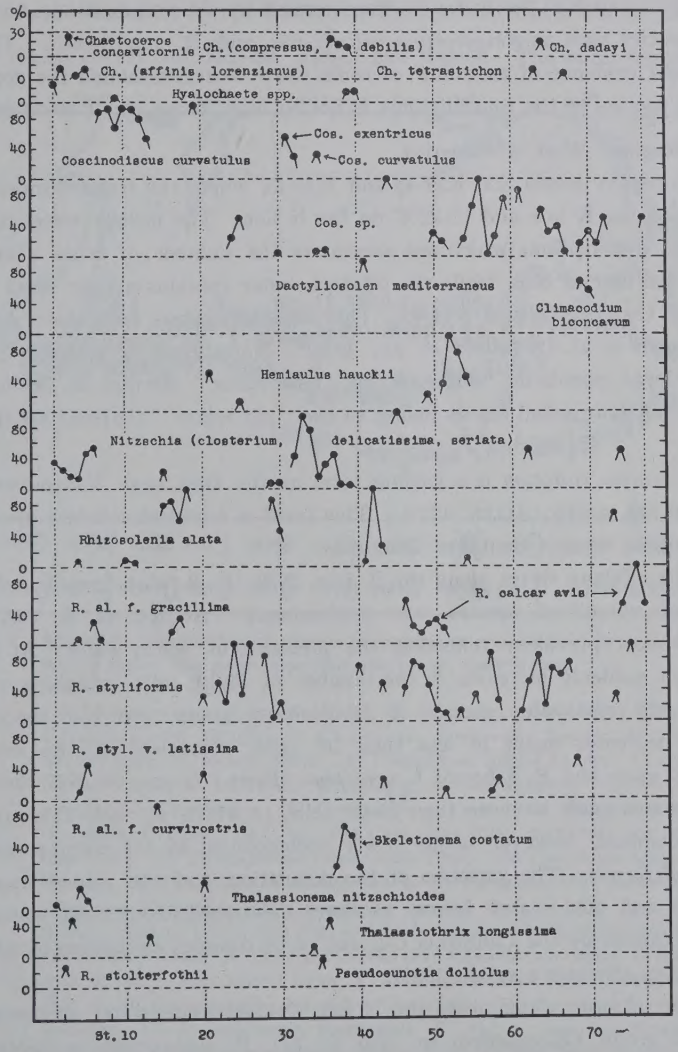

Fig. 5-b. Percentages of the cell number of important species to the total diatom cells (sampled on board the Nihon Maru).

At K37 and N30 the water is characterized by the accompaniment of warm-water species such as *Rhizosolenia calcar avis* and *R. styliformis*. This fact may show evidence of an inflow of some warm water, although the precentage of these species to the total diatoms is not so high, being about 20–24 per cent.

E Region; West off America

This region covers Sts. K39–48 and N36–45, where the water temperature is 16–18°C on the K line and 12–22°C on the N line. The inshore water is densely populated with diatoms which are present to the number of more than $42 \cdot 10^4$ cells to the liter at N38, while the offshore water contains a very small population less than 10^2 cells at N42–43. This tendency agrees with the report made by SVERDRUP et al. (SVERDRUP et al., 1938). Namely, it is probable that the inshore large population is due to the "new water" (fertile) on the one hand and the offshore small one is owing to the "old water" (barren) on the other hand.

Skeletonema costatum is a leading form in the area near Vancouver Island as ALLEN has stated (ALLEN, 1927). This form is found abundantly also at K48 in the coastal area of Southern California.

In the offshore water along the K line (K39–41) *R. alata* groups, which are cold-water ubiquitous species, are predominant. At K42–44 *R. calcar avis* becomes most prevalent reflecting the presence of warm water. At K45 the population suddenly increases to the number of $79 \cdot 10^2$ cells, which is occupied by only the cold-water species of *Hyalochaete* group. At K46 the count of diatoms decreases again to less than 10^2 cells, comprised of the cold-water species *R. alata* and *R. hebetata* f. *semispina* (Hens.) Gran. At K47 the population increases again to more than $16 \cdot 10^2$ cells, in which *R. heb.* f. *semispina* is still predominat, however being newly accompanied by the warm-water forms of *R. styliformis*. The variation of the population and the mixed appearance of warm and cold water forms, as above mentioned about those stations, are probably caused by the California Current or by complex circulation of water and some eddies (SVERDRUP et al., 1938).

In the offshore water along the N line (N45–41), cold-water species such as *Nitzschia* group, *Coscinodiscus* sp. (Fig. 6, (6)), *R. alata* group, or *Dactyliosolen mediterraneous* are leading forms respectively. But it must be noticed that Sts. N40 and N43 are characterized by warm-water forms such as *R. styliformis* contained in considerable number besides those cold-water forms.

F Region; Region of North Equatorial Current and North Pacific Current

This region covers Sts. K49–80, N18–27 and N46–68. The water temperature

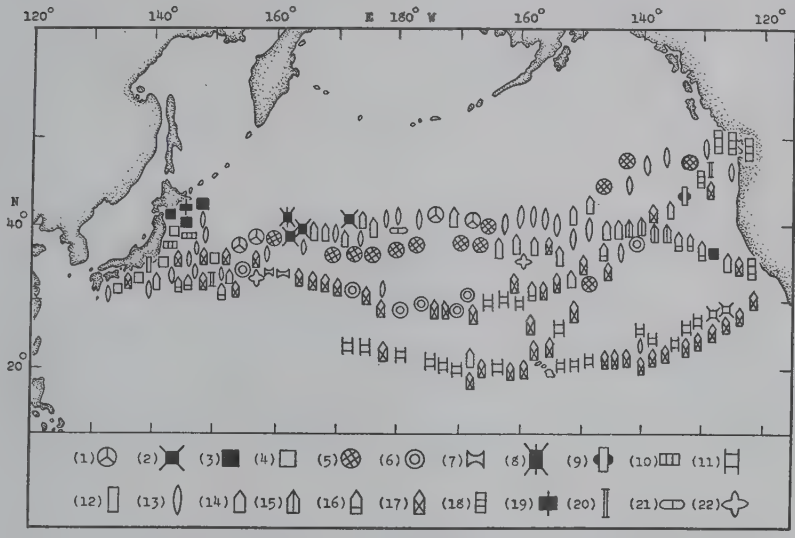

Fig. 6. Schematic distribution of diatom communities represented by symbols which denote the most important species on each station.
Symbols in the figure:
(1) *Asteromphalus heptactis* Ralfs, (2) *Chaetoceros atlanticus* Cleve, *C. concavicornis* Mangin, (3) *Chaetoceros compressus* Lauder, *C. constrictus* Gran, *C. debilis* Cleve, (4) *Chaetoceros affinis* Lauder, *C. curvisetus* Cleve, *C. didymus* Ehrenberg, *C. lorenzianus* Grunow, *C. messanensis* Castracane, (5) *Coscinodiscus excentricus* Ehrenberg, *C. curvatulus* Grunow, (6) *C.* sp. (Cells are very little, diameters are less than 30μ.), (7) *Climacodium biconcavum* Cleve, (8) *Corethron hystrix* Hensen, (9) *Dactyliosolen mediterraneus* H. Peragallo, (10) *Eucampia zoodiacus* Ehrenberg, (11) *Hemiaulus hauckii* Grunow, (12) *Leptocylindrus danicus* Cleve, (13) *Nitzschia delicatissima* Cleve, *N. longissima* (Brebisson) Ralfs, *N. seriata* Cleve, (14) *Rhizosolenia alata* Brightwell, *R. al.* f. *curvirostris* Gran, *R. al.* f. *gracillima* (Cleve) Grunow, (15) *R. al.* f. *indica* (H. Peragallo) Ostenfeld, (16) *R. calcar avis* M. Schultze, (17) *R. styliformis* Brightwell, *R. styl.* v. *latissima* Brightwell, (18) *Skeletonema costatum* Cleve, (19) *Thalassiosira decipiens* (Grunow) Jörgensen, *T. nordenskiöldii* Cleve, *T. subtilis* (Ostenfeld) Gran, (20) *Thalassiothrix longissima* Cleve and Grunow, (21) *Tropidoneis antarctica* v. *polyplasta* Gran and Angst, (22) Pennatae Schütt misc.

on the K line tends to be gradually high from about 18°C to 28°C, while that on the N line fluctuates between about 20°C and 28°C.

The region is almost entirely populated very scarcely by diatoms as is also B region, showing less than 10^2 cells to the liter. Samples taken from K53, 74, 75, 78 and N 60 do not include any plankton organisms. Allen & Lewis (1927) and Marumo (1955) also report that plankton organisms were very scarce in surface waters of lower latitudes in the North Pacific Ocean.

Collected diatoms are too scarce in number to obtain a perfect view of their community, but in general *Rhizosolenia styliformis* group (Fig. 6, (17)) is most prevalent, being accompanied by *Hemiaulus hauckii* and *R. calcar avis* as secondary components; sometimes *Climacodium biconcavum*, warm-water species of *Phaeoceros* (Fig. 5-a) and *Coscinodiscus* sp. (Fig. 6. (6)) are found.

Abundance in population of diatoms ($17{\cdot}10^2$ cells at K64) in the area to the northeast of the Hawaiian Islands may depend upon the presence of some "new water" high in nutrient salts, as has been reported by Graham (Graham, 1941). The increase of the count of diatoms and the presence of cold-water forms such as *Coscinodiscus* group at N19, may suggest some inflow from the northern part.

(2) *Distribution of other microplankton*

Though diatoms are the most significant in this investigation, such forms as tintinnods, dinoflagellates and copepods are also fairly important as secondary components of the microplankton communities. But on account of their small numbers a more detailed view than the following aspect is not possible to be obtained.

Cold-water tintinnods, *Acanthostomella norvegica* (Daday) Jörgensen, *Parafavella longidentata* n. sp. and *P. ventricosa* (Jörg.) Kofoid & Campbell are found, less than 60 total cells per litert in the Subarctic Current region to the north of 35° N. Warm-water tintinnods, *Dadayiella gaymedes* (Entz) Kofoid & Campbell and *Steenstrupiella steenstrupii* (Claparède & Lachmann) Kofoid & Campbell are seen less than 240 cells in the Kuroshio Extention region and off California (K33-35, N42).

Noctiluca scintillans Macartney occurs less than 30 cells only in the region neighbouring Japan and the Kuroshio Extension. A warm-water dinoflagellate, *Ceratium furca* (Ehr.) Dajardin, is distributed less than 30 cells in the Kuroshio Extension region and in the warm waters off California. Cold-water dinoflagellates, *Ceratium macroceros* (Ehr.) Cleve, *C. macro.* subsp. *gallicum* (Kof.)

Jörgensen, *C. tripos* (O. F. Mull.) Nitzsch and *C. inflatum* Kofoid are scattered less than 200 cells in total per liter in the northern cold waters. *Peridinium* spp. are found less than 150 cells in the cold water off California.

Small size copepods including their nauplius stage larvae are found ubiquitously in the whole area. But there is a tendency for only less than 55 individuals per liter to be fouud in the warm water area of latitudes lower than 35° N, while in the cold water area of higher latitudes than 35° N more than 200 are often seen.

3. Discussion

In the above-noted sea region of the Kuroshio Extension the total population of microplanktons is very small. Such a condition agrees well with the conclusions reached by Marumo (1955) and the IGY Observations (J. M. A. 1959) in the same region. The poor production in this area may probably depend upon the scantiness of nutrient salts. It may be noteworthy that the corresponding non-productive area contains phosphate-phosphorus at only 0.04–0.11 μg-atoms/l on the one hand whilst the productive Oyashio water is considerably richer in phosphate-P to 0.92–1.36 μg-atoms/l on the other hand, as shown by the IGY Observations.

It is recognized that there exists a fairly clear discontinuity of microplankton associations in the population as well as in the composition at about the 35° N line in the central part of the North Pacific Ocean. That is to say, the water to the south of this line contains very small population characterized by warm-water components, while on the other hand in the area north of that line the population being occupied by only cold-water forms suddenly increases to a considerable number. But that does not always mean that the higher the latitude the greater the population. Allen (1927) and Кобленц-Мишке (1961) report poor productivity in the far northeastern North Pacific Ocean, and Ohwada & Kon (1963) also find less than 10^3 individuals per liter of water near 45° N in the part to the south of the Aleutian Islands. Thus, the large amount of population in the water of the Subarctic Current near 40° N may be decreased again gradually in the higher latitude area. It is noticeable that *Nitzschia* group and *Coscinodiscus* group are found to be predominant in the water of the Subarctic Current in summer not only in the present survey but also in the reports by Marumo (1955) and Ohwada & Kon (1963). Thus these groups may be considered as an important indicator of that water in summer.

It may be reasonably considered that the water around 40° N, 140–150° W is usually in the end of the Subarctic Current which contains hardly any warm-water plankton. But in the present survey warm-water forms such as *Rhizosolenia calcar avis* and *R. styliformis* are found in fairly high percentages from 21 to 83 per cent at stations K37, N30, N43 and N40. Additionally, the water at K33–35 and N42 is characterized by presence of warm-water tintinnods, *Dadayiella gaymedes* and *Steenstrupiella steenstrupii*. These facts may show obviously the existence of an influence of some warm water, and it would be interesting to trace the origin of that warm water. It may be unreasonable to attribute the origin of the warm water to the warm Kuroshio Extension water, far beyond the North Pacific.

Tibby (1941) reports that the water off Cape Blanco (about 43°N) contains about 35 per cent of warm equatotial water because of the California Counter Current. The transport of warm equatorial water to the north (to near N40) appears to be largely accounted for by the inshore northward flow of the California Coastal Counter Current. Sverdrup et al. (1942) recognize the existence of a clockwise eastern gyral in the eastern North Pacific with its center to the northeast of the Hawaiian Islands.

It seems probable that the warm-water plankton in above mentioned stations (except N40) show some traces of the warm water transported along the outer edge of the gyral.

4. Summary

(1) An obvious clear microplankton boundary is found by analysis near the line of 35°N in the Central North Pacific Ocean.

(2) From the components of microplankton association it is confirmed that the water in higher latitude than 40°N in the Subarctic Current scarcely contains Kuroshio features as Marumo (1955) has stated.

(3) The water in the Subarctic Current is densely populated with diatoms; it is characterized by the predominance of *Nitzschia* group (Fig. 6, (13)) and *Coscinodiscus* group (Fig. 6, (5)).

(4) The water in the North Equatorial Current and North Pacific Current contains very small population of diatoms of which *Rhizosolenia styliformis* group (Fig. 6, (17)) and *Hemiaulus hauckii* (Fig. 6, (11)) are the most important.

(5) In the water off California the influence of the warm equatorial water is found up to fairly northern point.

Acknowledgment: The authors wish to express their hearty thanks to Dr. R. MARUMO for his useful suggestions and encouragement. Thanks are also due to the members of the observation staff of the "Nihon Maru" and the "Kaiō Maru", by whom valuable plankton samples were collected, and also due to Prof. Harold M. LANE for his reading of the manuscript.

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—Distribution of the microplankton and their relation to the character of water masses in the Bering Sea and northern North Pacific Ocean in the summer of 1960 -

By

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(Received January 21, 1963)

1. *Introduction*

During the cruise of the "Oshoro Maru", a training ship of Hokkaido University, from June to August in 1960, samples of surface plankton were taken from the stations as are shown in Fig. 1. Fifty-seven stations were

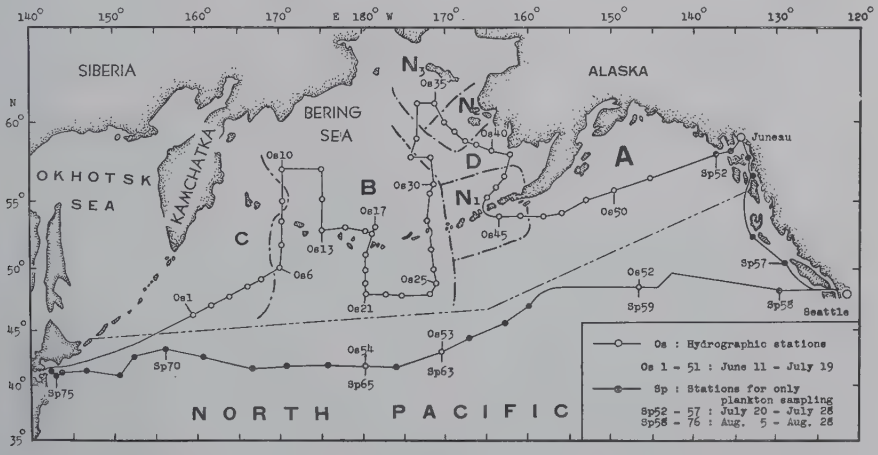

Fig. 1. Location of the sampling positions (the numerals on the observational lines show station numbers), and demarcation of regions (A-N_3) which are set according to the characteristics of diatom communities.

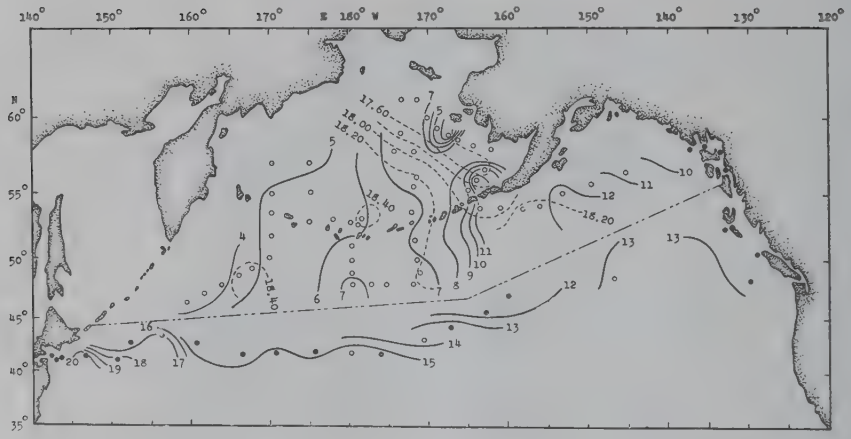

Fig. 2. Horizontal distributions of water temperature (full line) and chlorinity (broken line) at the surface.

occupied on the outward track from Hakodate, Japan, to Seattle, Washington, U. S. A., via Juneau. On the homeward course samples were gathered at nineteen stations traversing the North Pacific. These samples were provided to the authors at their disposal for investigation of microplankton. The hydrographical data and other details of this cruise had been published (Fac. Fish. Hokkaido Univ., 1961).

Concerning the microplankton in the Bering Sea and the northern North Pacific Ocean, many investigations have been made for instance by such as following researchers; Aikawa (1935, 1936), Tsuruta & Chiba (1952), Motoda & Kawarada (1955), Takano (1958), and Karohji (1958, 1959) whose reports are based on the net samples, whilst Allen (1927, 1929), Marumo (1955, 1956), Kawarada & Ohwada (1957), and Kawarada (1957) whose informations are founded on the materials by dipping water. Their results do not always well agree with each other not only in populations but also in constituents of microplankton. In the present microplankton analysis it may be recognized that there is a central oceanic water mass by which the waters in the Bering Sea are divided into the eastern neritic water and the western one, in the general situation.

Sampling methods are detailed in the preceding paper (Ohwada & Asaoka,

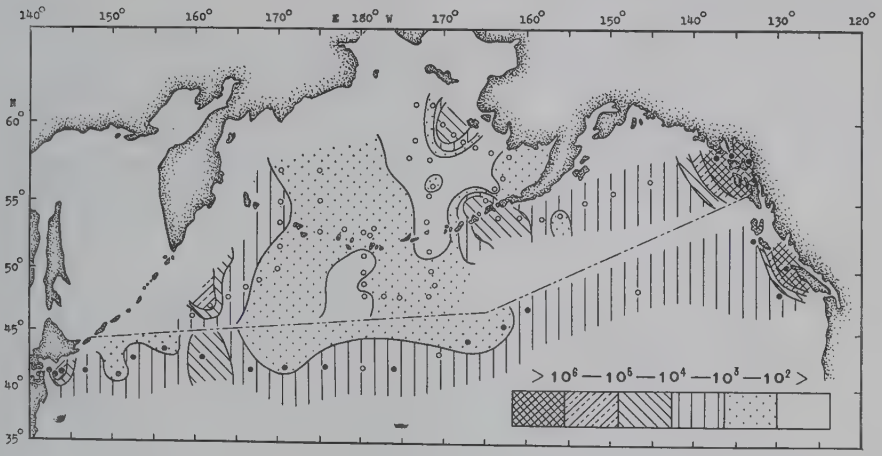

Fig. 3. Distribution of total number of diatom cells in one liter of surface sea water.

1963); shortly, the diatoms in 330 cc surface water are concentrated by decanting and centrifugalizing; counting and identification are made under a microscope. In this paper the "cell number" represents that of microplankton in one liter of water. Not only for the convenience of discussion but also because of the long interrupted interval, the distribution of microplankton in the northern area on the outgoing course is mentioned first and that of the southern area on the homeward course is described in another chapter.

2. *Northern investigated area*

(1) *Characteristics of microplankton population*

There exist very densely populated regions, where the diatom numbers reach 10^4—10^7 cells per liter of water, along generally coastal areas as follows; namely, the sea southeast of the Kamchatka Peninsula, near Nuvivak Island northwestward to the Bristol Bay, the sea area from the tip of the Alaska Peninsula to the Fox Islands, and the coastal zone from Juneau to Seattle (Fig. 3). The maximum number reaches 3,082,000 cells per liter at Sp 54 near Juneau, and 88 per cent of this number is occupied by *Skeletonema costatum.*

In the extensive areas from the central part of the Bering Sea to the southern portion across the Aleutian Islands, the diatom numbers are less than 10^3 cells, especially they do not amount to 10^2 cells in the two parts of Os 18—21 and Os

27—34.

The count of dinoflagellates is relatively high in the coastal portions near the tip of the Alaska Peninsula and close to Vancouver Island. Especially at Os 42, at the mouth of the Bristol Bay, the amount of total dinoflagellates exceed $8 \cdot 10^4$ individuals which are occupied to 99 per cent of these numbers by *Peridinium* sp. (very similar to *Peridinium thorianum* Paulsen). Tintinnods are scattered in the area outside of the Bering Sea less than 500 individuals in the maximum.

(2) *Important components*

The diatom species which most predominantly appear in the present samples are as follows;

Chaetoceros-Phaeoceros Gran group,
Chaetoceros atlanticus Cleve
Chaetoceros concavicornis Mangin
Chaetoceros convolutus Castracane
Chaetoceros-Hyalochaete Gran group,
Chaetoceros compressus Lauder
Chaetoceros constrictus Gran
Chaetoceros debilis Cleve
Chaetoceros decipiens Cleve
Corethron hystrix Hensen
Denticula marina Semina
Fragilaria islandica Grunow
Nitzschia closterium (Ehr.) W. Smith
Nitzschia seriata Cleve
Rhizosolenia alata Brightwell
Rhizosolenia hebetata f. *hiemalis* Gran
Rhizosolenia hebetata f. *semispina* (Hensen) Gran
Skeletonema costatum (Greville) Cleve

The following cold-water species of dinoflagellates are most abundantly found along the eastern coastal region.

Ceratium fusus (Ehr.) Dajardin
Ceratium longipes Gran
Peridinum sp. (very similar to *Peridinium thorianum* Paulsen)

Though the role of tintinnods in the microplankton associations is not so

significant in the present study, such as following cold-water tintinnods are frequently found.

Acanthostomella norvegica (Daday) Jörgensen
Codonellopsis frigida Hada
Parafavella jörgenseni Hada
Parafavella longidentata n. sp.
Parafavella subcylindrica Hada
Parafavella ventricosa (Jörg.) Kofoid & Campbell
Ptychocylis drygalskii Brandt

(3) *Diatom communities with reference to the hydrographic conditions*

From the characteristics of the diatom communities in respect to their density as well as to their components (Figs. 4, 5), the area investigated may be divided into the following seven regions (Fig. 1).

A Region

In this region, including stations Os 47—51, the water temperature is the highest (10—12°C) on the outward cruise line to Juneau (Fig. 2). The diatom population is moderate, showing 10^3—$4 \cdot 10^3$ cells per liter. The leading form is *Nitzschia* group, additionally *Chaetoceros-Phaeoceros* group, *Rhizosolenia alata* and *R. hebetata* f. *semispina* are found as secondary components.

The coastal region from Juneau to Seattle covering Sts. Os 52—55 and Os 57, is the most productive area in the present investigation. The amounts of total diatoms are more than 10^5 cells which are almost occupied by *Skeletonema costatum*. At Sts. Os 56 and Os 58 the diatom population is relatively small, less than $2 \cdot 10^3$ cells, whilst *Peridinium* sp. is abundant showing $3 \cdot 10^3$ individuals.

B Region

This region corresponds to the area of the minimum population of plankton. Oceanic cold-water species such as *Corethron hystrix*, *Denticula marina* and *Phaeoceros* group are widely distributed as if the water is flowing out from the central portion of the Bering Sea to the northern North Pacific passing over the Aleutian Ridge. While the considerable occurrence of *Hyalochaete* group and *Fragilaria islandica* at Sts. Os 15—18 and Os 21, may suggest some intrusion of different waters from south towards north.

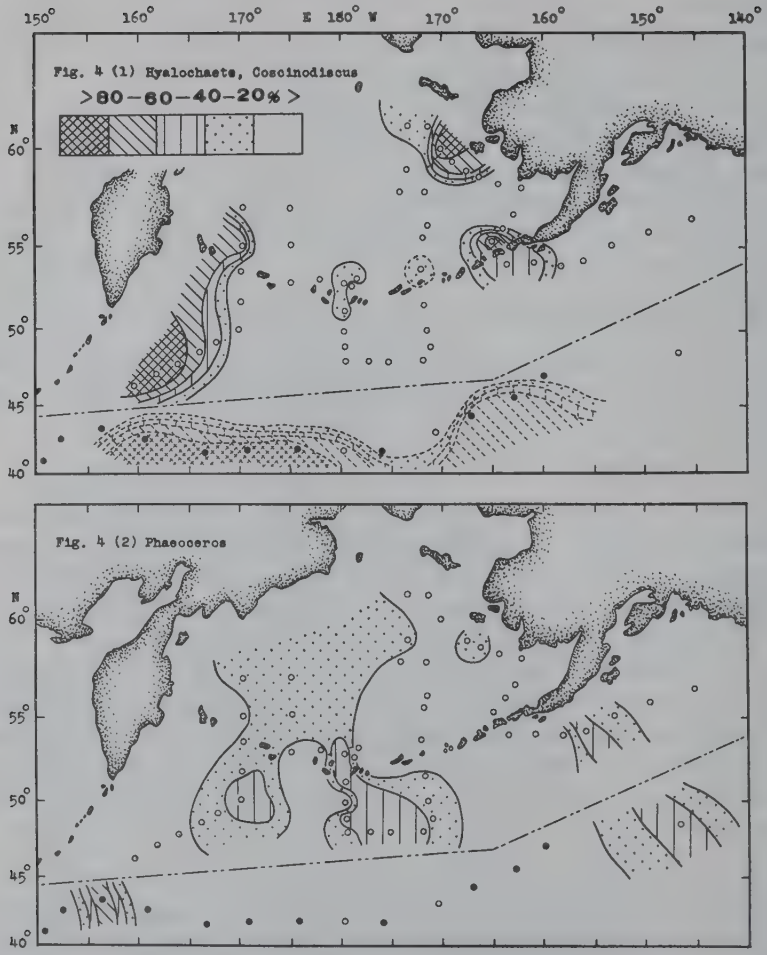

Fig. 4. Occurrence of (1) *Chaetoceros-Hyalochaete* (full shade) and total *Coscinodiscus* (broken shade), and (2) *Ch.-Phaeoceros* in percentage of total diatoms, respectively.

C Region

This region is populated with diatoms in considerable density, and the water

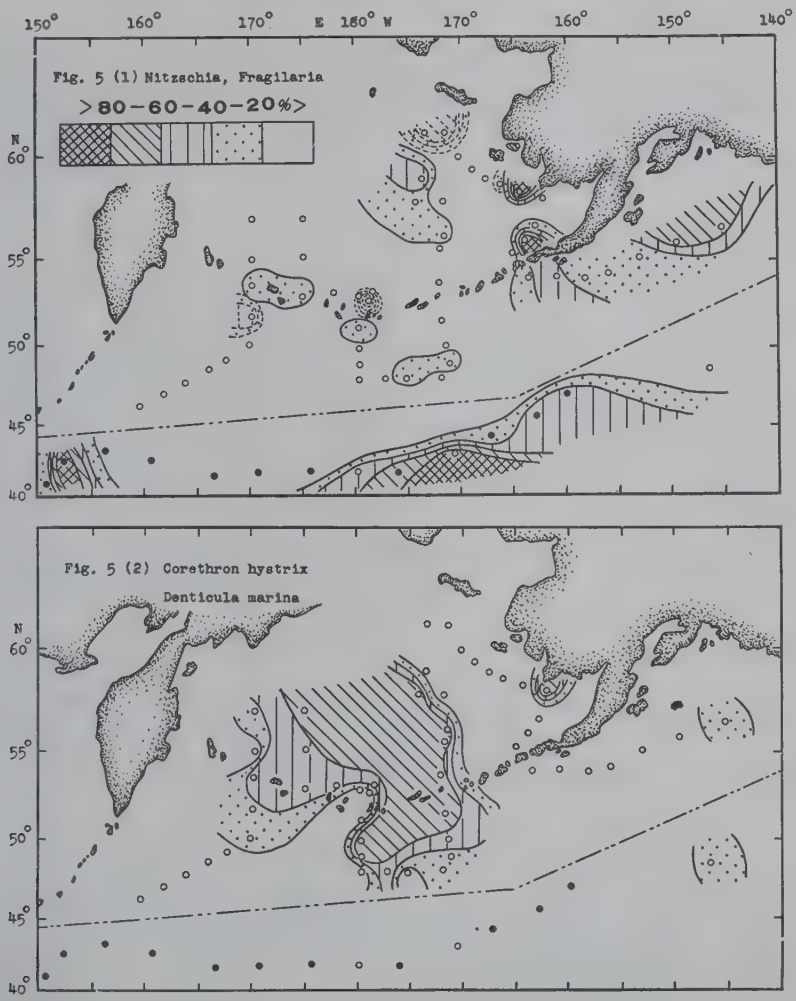

Fig. 5. Occurrence of (1) *Nitzschia* (full shade) and *Fragilaria islandica* (broken shade), and (2) *Corethron hystrix* and *Denticula marina* in percentage of total diatoms, respectively.

is characterized by the predominance of *Hyalochaete* group. The water temperature is the lowest, less than 5°C, of the area investigated.

D Region

This region covering the area of the Bristol Bay, Sts. Os 39—41, Os 31 and Os 33, is characterized by predominance of *Nitzschia* group with exception of Os 41. From the prevalency of *Nitzschia* group, the water of this region may be connected with the water of the Gulf of Alaska where this group is the most significant.

N_1 Region

This region covers Sts. Os 42—46 crossing over the Alaska Peninsula, where the water temperature is relatively high, showing 8—12°C. The water is populated with dinoflagellates as well as diatoms in considerable density. The predominant species of diatoms are all neritic cold-water forms such as *Hyalochaete* group and *Nitzschia* group. Counts of dinoflagellates reach 81,800 individuals at Os 42 and 19,500 at Os 45, respectively. More than 95 per cent of them are occupied by *Peridinium* sp. (very resemble to *Peridinium thorianum* Paulsen).

Thus the appearence of the similar plankton associations on both sides of the Alaska Peninsula, may show an existence of comings and goings of waters across the Unimak pass etc.

N_2 Region

This region includes Sts. Os 36—38, where the water temperature decreases to 7—4°C. The count of diatoms is relatively high, being about $2 \cdot 10^3$—$14 \cdot 10^3$ cells which are almost occupied by only *Hyalochaete* group.

N_3 Region

In this region covering Sts. Os 34—35, total population of diatoms is very small, less than 120 cells, as in B or C region. But the water is distinguished from those of the two regions by the predominancy of *Fragilaria islandica*.

Thus above-mentioned characteristics of diatom communities in each region are briefly summarized as following Table 1.

Table 1. Characteristics of diatom communities and other factors in each region.

Region	A	B	C	D	N_1	N_2	N_3
Total number of diatoms/l	10^3—$4\cdot10^3$	10^2—10^3	$2\cdot10^3$—10^5	$<10^2$	$3\cdot10^4$—10^5	$2\cdot10^3$—$2\cdot10^4$	$<2\cdot10^2$
Hyalochaete (%) percentages to the total numb. of diatoms	——	thin (0—36)	dense (47—98)	——	dense (53—79)	dense (64—98)	moderate (21—33)
Phaeoceros (%)	thin (4.0—43)	dense (0—56)	thin (1.0—54)	thin (0—22)	scarce (0—3.5)	thin (1.0—26)	scarce (0—4.2)
Corethron hystrix (%)	scarce (0—9.6)	moderate (5.4—29)	scarce (0—10)	——	—	——	——
Denticula marina (%)	scarce (0—15)	dense (3.1—75)	——	moderate (0—69)	——	——	——
Fragilaria (%)	——	thin (0—80)	——	——	——	——	dense (62—79)
Nitzschia (%)	dense (24—73)	moderate (1.0—34)	scarce (0—13)	dense (7.4—100)	dense (30—100)	thin (0—10)	——
Rhizosolenia (%)	moderate (4.8—61)	scarce (0—23)	scarce (0—3.9)	——	scarce (0—3.6)	——	—
Surface water temp. (°C)	11—12	5—7	< 5	7—8	10—12	4—7	7
Surface water chlorinity (‰)	18.00—18.28	18.00—18.40	18.30—18.40	<17.80	<17.70	<17.60	<17.60
Dissolved oxygen (cc/l)	6.5—7.0	6.0—7.5	>7.5	7.0—7.5	6.0—7.0	7.5	>7.5
Phosphate-P (μg-atoms/l)	0.8—1.0	0.2—1.4	>1.2	<0.2	0.2—0.6	<0.2	<0.2
Silicate-Si (μg-atoms/l)	0—5	5—20	>20	0—5	0—5	0	0

3. Southern investigated area

This area includes Sts. Sp 59—76 on the homeward course. As a whole, the water is relatively densely populated with diatoms, being largely occupied by following important species;

Chaetoceros atlanticus Cleve
Chaetoceros concavicornis Mangin
Chaetoceros convolutus Castracane
Chaetoceros compressus Lauder

Coscinodiscus radiatus Ehrenberg
Coscinodiscus sp.
Nitzschia seriata Cleve

At the stations Sp 59 and Sp 72 *Phaeoceros* group occupies more than 55 per cent of total diatoms. In the extensive area covering Sts. Sp 60—71 (except Sp 70), *Nitzschia seriata* and *Coscinodiscus* group are the most prominent species. Such diatom communities agree very well with those in the Subarctic Current reported in the preceding paper (Ohwada & Asaoka, 1963). At Sp 72 the diatom population is very small, less than 300 cells per liter. There are no conspicuous species, but cold-water forms such as *Asteromphalus heptactis* (Brébisson) Ralf, *Nitzschia seriata*, *Rhizosolenia alata*, and *Thalassiothrix longissima* Cleve & Grunow are found. In the area off Hokkaido covering Sts. Sp 73—76, the catches are greater than $5 \cdot 10^3$ diatom cells to the liter. Cold-water species such as *Chaetoceros compressus* and *Chaetoceros decipiens* Cleve are leading forms. In addition, warm-water species such as *Climacodium biconcavum* Cleve, *Chaetoceros affinis* Lauder and *Chaetoceros curvisetus* Cleve are found.

4. Discussion

In the general situation, it is now an established oceanographic concept that there exists a counter-clockwise gyre moving very slowly in the Bering Sea in the summer months (Barnes & Thompson, 1938; Mishima & Nishizawa, 1955; Hirano, 1958). In the present investigation, sea conditions in the eastward part (west of the Bristol Bay) and westward portion (near Attu Island) of the Bering Sea fairly well agree with the above mentioned ideas, but those in the area from the central part of the sea to the surrounding portion from Adak Island to Umnak Island contradict their predictions.

From the characteristics of the diatom communities in the present study, especially from the distribution of *Phaeoceros* group, *Corethron hystrix* and *Denticula marina*, it may be assumed that the central water of the Bering Sea seems to be flowing out towards south passing through the channels among the Aleutian Islands (Figs. 4, 5). The assumption may be emphasized by the horizontal distribution of phosphate-P and silicate-Si in the surface water. Further more, the existence of the southwestery current between Umnak Island and Adak Island is confirmed by the dynamic topography (Fig. 6).

The northeastward flow into the Bering Sea from the North Pacific passing

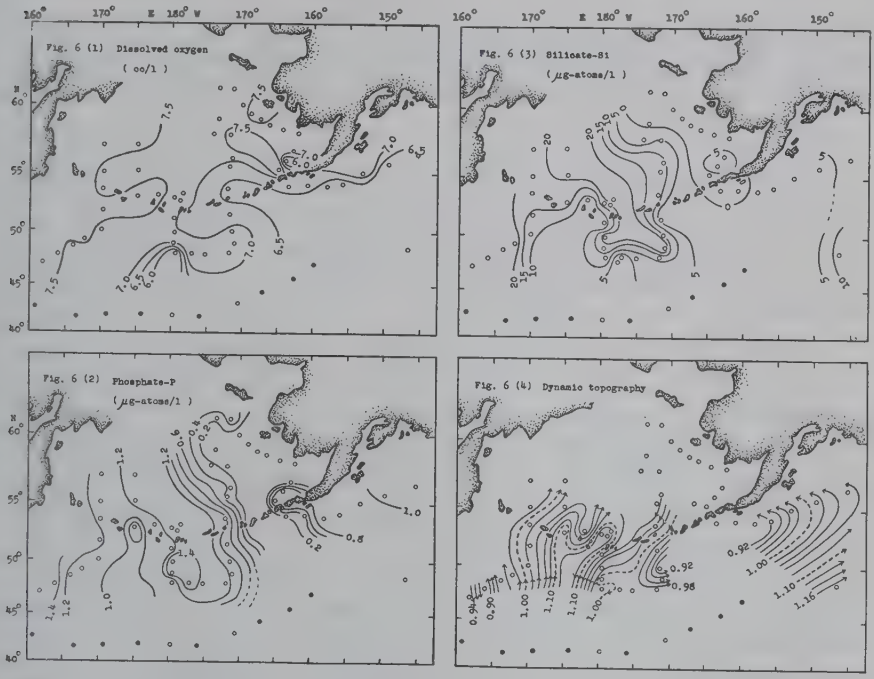

Fig. 6. Horizontal distribution of (1) Dissolved oxygen (cc/l), (2) Phosphate-phosphorus (μg-atoms/l); and (3) Silicatesilicon (μg-atoms/l); (4) Dynamic topography of ΔD at a depth of 10 m based on the reference level of 1,000 m.

over the Aleutian Ridge near Attu Island, is approved by the intrusion of *Hyalochaete* group and *Fragilaria islandica* into the area, and also by chemical factors as well as the dynamic topography.

Barnes & Thompson (1938) and Mishima & Nishizawa (1955) have reported as if the counter-clockwise flow to the west of the Bristol Bay originates in the eastward flow along the north side of the Aleutian Islands. But from the distribution of microplankton in the N_1 region in the present study, it may be suggested that there exists a fairly intensive direct intrusion of the North Pacific water into the Bering Sea across the Unimak Pass etc. That is to say, because the very similar microplankton associations in the populations as well as in the constituents (for instance, cold-water *Hyalochaete* group, *Nitzschia* group and *Peridinium* sp.) appear very closely and continuously, in spite of the

fact that this region is separated into two portions by the Alaska Peninsula and the Aleutian Islands. It would be required more detailed observations or data to more clarify physical and chemical sea conditions in this area.

5. *Summary*

(1) The planktological and some oceanographical work performed on the cruise of "Oshoro Maru" made during the summer of 1960 to the Bering Sea and the northern North Pacific Ocean has been outlined.

(2) From the characteristics of the diatom communities, the area investigated is divided into seven regions and discussed.

(3) From the distribution of diatoms and chemical factors in the surface water, a southward outflow of the water from the central Bering Sea passing over the Aleutian Ridge, is suggested.

(4) In the area occupied by the homeward cruise of "Oshoro Maru", *Nitzschia* group and *Coscinodiscus* group are the most predominant species of diatoms, corresponding to those of the Subarctic Current in the preceding report (Ohwada & Asaoka, 1963).

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On an Estimation of the Origin and Drifting Speed of Ice appearing off the Coast of Hokkaido

— Study on Sea Ice in the Okhotsk Sea (III) —

By

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(Received January 25, 1963)

Abstract: Succeeding to the preceding papers on the present thesis (WATANABE, 1963a, 1963b) in which the major part of drift-ice appearing off the coast of Hokkaido in the Okhotsk Sea has been assumed as coming from somewhere east off Sakhalin, here in the present paper is given a diagrammatic method computing the growth of a southward drifting ice and then estimating its origin and drifting speed from such informations as its arrival date at the coast and its thickness. Using this method, it has been estimated that the drift-ice observed off the coast near Monbetsu in Hokkaido on Dec. 23, 1960 ought to have been born near the east offing of northern Sakhalin slightly north of 50°N parallel at about the end of November and drifted southward towards the coast with an average speed of 0.8 kt or faster, and also that the drift-ice of 30-50 cm in thickness observed off Monbetsu on Jan. 4, 1961 ought to have been born in the area off about the northern tip of Sakhalin at about the end of November in 1960 and drifted southward with an average speed of 0.6—0.8 kt.

1. Introduction

In the preceding two papers on the present thesis, the major part of drift-ice appearing off Hokkaido has been assumed as coming from somewhere east off Sakhalin (WATANABE, 1963a, 1963b). Then, there stands a question; how far north comes the drift-ice from and how fast speed drifts the ice with? One of ways answering the question can be derived from such informations as the thickness of ice when it reaches the coast and as the date of its arrival.

The three chunks of ice shown in Fig. 1 measured at 45–60 cm in thickness ran ashore near Abashiri Harbor on a stormy day about Jan. 20, 1957, which are pieces of the first appeared drift-ice at the coast in the winter. As has been mentioned in the first paper on the present thesis, the first appearing drift-ice

Fig. 1. Three chunks of the first arrived drift-ice of 45–60 cm in thickness run ashore near Abashiri Harbor in January of 1957. Such considerably large thickness usually observed about the first appearing drift-ice suggests its origin in farther northern area in the Okhotsk Sea.

every winter is usually of 30 to 50 cm in thickness, not about 20 cm or thinner, though the newly formed sea ice has developed to only several centimeters in thickness until that period. This fact suggests that the drift-ice has sufficiently grown up under a considerably large integrated coldness before reaching the coast of Hokkaido, in other words, that it has travelled southward from a fairly farther north in the Okhotsk Sea.

The thickness of a drift-ice represents an integrated coldness denoted by the name of "degree days of frost" acted on it during southward drift after its formation. Accordingly, if there are some informations on the thickness of a drift-ice and on the date of its arrival at the coast, one may estimate by computing the amount of degree days of frost acted on the ice, the location where the ice forms together with some range of its drifting speeds, when the general drifting route is assumable. Here, is presented a diagrammatic method of computing the amount of degree days of frost acted on the drift-ice arrived at the coast of Hokkaido after southward drift, then are discussed its origin, its formation date, and its average speed of drift.

2. *Diagrammatic method of computing the growth of an ice in southward drift*

Imagine a sea ice forming at a station **A** in a northern sea region on a certain date f_A and simultaneously starting on a southward drift with a speed of v. The ice is to pass through a station **B** south of St. **A** in a distance of $\overline{\mathbf{AB}}$ on the data t_B where $t_B = f_A + \overline{\mathbf{AB}}/v$. Then, it will reach a farther southern station **C** at a distance of $\overline{\mathbf{BC}}$ measured from St. **B** on the date t_C where $t_C = t_B + \overline{\mathbf{BC}}/v$. This relation is illustrated in the time(t)—temperature(θ) diagram in Fig. 2, where three curves of air temperature only below 0°C at St. **A**, **B**, and **C** are given, which are said here the "*temperature curves*", and the dates of the first ice formation at St. **A**, **B** and **C** are shown by f_A, f_B and f_C, respectively, on the t-axis. As the point $\mathbf{F}_A$ gives the air temperature at St. **A** on the date f_A

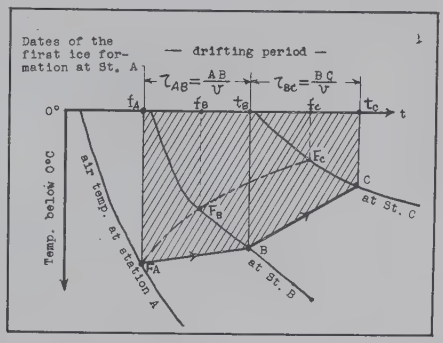


Fig. 2. Time-temperature diagram for computing the amount of "degree days of frost" acting on an ice in southward drift from a northern location of St. **A** through St. **B** towards a southern location of St. **C** with a speed of v.

when the ice starts, and the points **B** and **C** the air temperatures at St. **B** and **C**, respectively, on the dates when the ice reaches each station, the temperature condition acting on the drifting ice can be represented by the undulating line $\mathbf{F_A}\rightarrow\mathbf{B}\rightarrow\mathbf{C}$ in the diagram. Though the line $\mathbf{F_A}\rightarrow\mathbf{B}\rightarrow\mathbf{C}$ undulates, it is said here "*drifting curve*" for convenience, because it ought to become a continuous curve when air temperature at sufficiently many stations along the drifting route are available. Then, the shaded area enclosed by f_A $\mathbf{F_A}$ **B C** t_C gives the degree days of frost acting on the ice during its southward drift from St. **A** through St. **B** then to St. **C**. And as the curve $\mathbf{F_A}$—$\mathbf{F_B}$—$\mathbf{F_C}$, which is said here the "*first ice formation curve*" again for convenience, represents the temperature condition when the new ice first forms at each station along the drifting route of ice, the right-hand and lower side from the *first ice formation curve* means the "*ice-developing domain*" in the diagram. In other words, a drift-ice coming into this domain continues its growth corresponding to the amount of degree days of frost acting on it during drifting in the domain, whereas an ice drifting in the left-hand and upper side from the *first ice formation curve*, i. e. the outside of the *ice-developing domain*, does not develop but tends to melt away because the water there is not yet cooled to the freezing temperature.

Now inversely, imagine that a drift-ice which origin is unknown arrived at St. **C** on a certain date t_0 after a southward drift from some northern location, its *drifting curve* in the diagram are traceable for a given drifting speed. The air temperature at St. **C** on the data t_0 is fixed at the point **C** on the tempera-

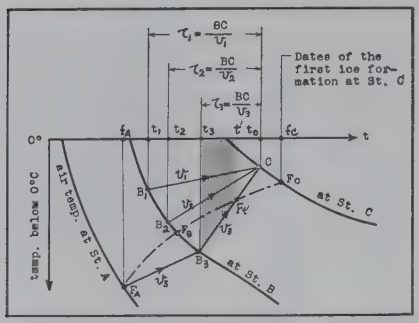


Fig. 3. Time-temperature diagram for computing the origin and formation date and southward drifting speed of an ice arriving at a southern St. **C** on the date of t_c.

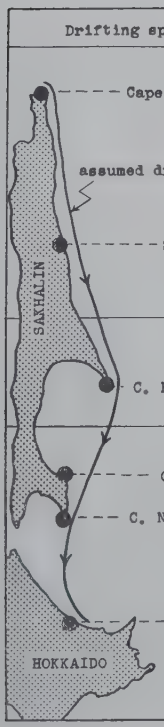
-ture curve of St. **C** as in Fig. 3. Giving a drifting speed at some small amount of v_1, the ice is to have started at St. **B** on the date of $t_1(=t_0-\overline{\mathbf{BC}}/v_1)$ under the temperature $\mathbf{B}_1$, then the *drifting curve* is drawn as $\overline{\mathbf{B}_1\mathbf{C}}$ in the diagram. Since the *drifting curve* $\overline{\mathbf{B}_1\mathbf{C}}$ lies in the outside of the *ice-developing domain*, such drift with v_1 is impossible for the ice in question. Similarly, a drift represented by the *drifting curve* $\mathbf{B}_2\mathbf{C}$ with a somewhat faster spead of v_2 also is impossible, because $\overline{\mathbf{B}_2\mathbf{C}}$ still lies in the outside of the *ice-developing domain*. But, if a more faster speed of v_3 is assumed for the ice's drift as in Fig. 3, the ice is to have passed through St. **B** on the date of $t_3(=t_0-\mathbf{BC}/v_3)$ which is after the date of the first ice formation there, i. e., it passes through the point $\mathbf{B}_3$ in the diagram. As the point $\mathbf{B}_3$ is in the *ice-developing domain* in this case, such drift with the speed v_3 is possible for the ice in question. If the thickness of the ice on the date t_0, when it arrived at St. **C**, just corresponds to the degree days of frost measured by the area enclosed by $t_3\,\mathbf{B}_3\,\mathbf{F}_{t'}\,t'$, the ice can be thought to have been born at St. **B** on the date t_3 and have drifted southward towards St. **C** with the speed of v_3. When the observed thickness exceeds the one corresponding to such measured amount of degree days of frost, the process tracing the *drifting curve* must be continued to a farther northern station in the diagram, because the origin of the ice is to be in a northern location than St. **B**. Then, assuming that the *drifting curve* reaches the point $\mathbf{F}_A$ on the *temperature curve* of St. **A** in the case of the speed v_3, and also that the amount of degree days of frost measured by the area enclosed by $f_A\,\mathbf{F}_A\,\mathbf{B}_3\,\mathbf{C}\,t_0$ just corresponds to the thickness of

the ice observed at St. **C** on the date t_0, it can be concluded that the ice in question has been born at St. **A** in the date f_A, i. e., the date of the first ice formation at St. **A**, and has simultaneously started on its southward drift towards St. **B** and **C** with the speed of v_3. Thus, we can estimate by the diagrammatic method the origin and the formation date and also the average drifting speed of a drift-ice arrived at a southern locaton, when its thickness and arrival date are observed and also its general drifting route is assumable.

3. Practical estimation of the origin and formation date and average speed of the drift-ice arrived at the coast of Hokkaido

For computing the ice growth during its southward drift, or the degree days of frost, then estimating the origin and the formation date and the average drift-

Tabel 1.



Drifting speed (kt)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Cape of Elizabeti	136	91	68	54	45	39	34	30	27
Station 32059	98	66	49	39	33	28	24.5	22	19.5
50°N	78	52	39	31	26	22.5	19.5	17.5	15.5
C. Kitashiretoko	61	41	30	24	20	17.5	15	13.5	12
48°N	50	33	25	20	16.5	14	12.5	11	10
C. Airō	35	23	17.5	14	12	10	9	8	7
C. Nakashiretoko	24	16	12	10	8	7	6	5.5	5

Drifting periods (in days) of an ice necessary to travel from each station for Monbetsu

ing speed of the ice, it is necessary as explained in the preceding section that the general drifting route is assumed and that the air temperatures and the dates of the first ice formation at several stations along the drifting route are known.

The drifting route of ice off the coast off Hokkaido has been described in the preceding two papers on the present thesis, as the major part of the drift-ice appearing there comes southward from the east offing of the Cape of Nakashiretoko (Aniva), one of the southern tips of Sakhalin, towards the coast of Hokkaido with some speeds of 0.3 kt or faster (WATANABE, 1963a, 1963b). Considering to the usually observed thickness of 30–50 cm of the first appearing drift-ice there, the ice must be thought as coming from farther northern areas than southern Sakhalin, such as the east offing of middle or northern Sakhalin. Such reasonably assumable drifting route is drawn in the inset chart of Table 1. And in the Table are presented the drifting periods (in days) for a drift ice necessary to travelling to the coast near Monbetsu from the eight stations in Sakhalin area

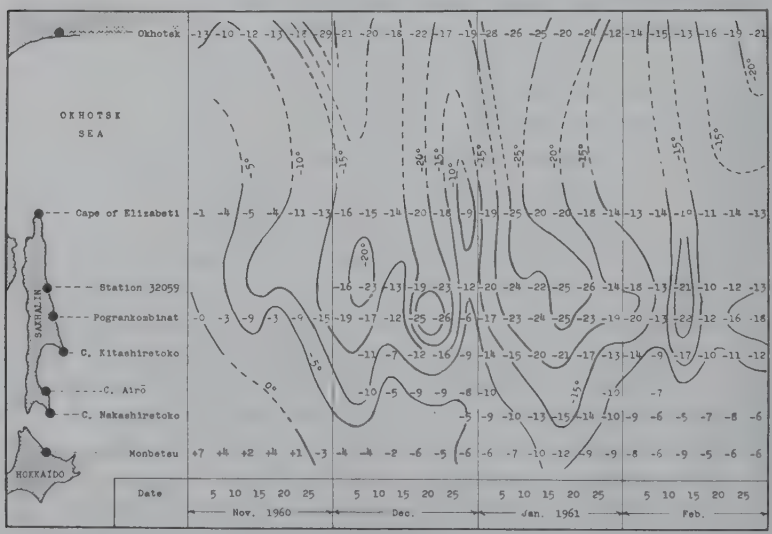


Fig. 4. Isopleth of air temperature (5-day mean) along the western side of the Okhotsk Sea in the period from November of 1960 to the succeeding February. The amounts of 5-day mean air temperature (in °C) at each station are plotted on the horizontal line corresponding to the latitude of each station, and the dates at 5-day intervals are presented in lower scale.

along the assumed drifting route for sereral given speeds of southward drift from 0.2 to 1.0 kt. The southward ice drift from the Cape of Elizabeti, the northern tip of Sakhalin, to Monbetsu requires, for instance, a very long period of about 136 days in the case of 0.2 kt, whereas a fairly shorter period of about 27 days when the drifting speed is assumed at 1.0 kt as seen in Table 1.

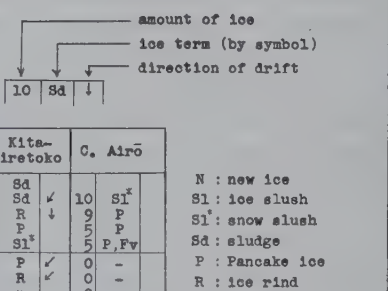
Referring to the air temperature on each station along the drifting route, an isopleth of air temperature is presented in Fig. 4 for the western coast of the Okhotsk Sea in the period from November in 1960 to February in 1961, where 5-day mean air temperature (in °C) are printed on the lines corresponding to each latitude of the eight stations shown in the inset chart, and each isotherm is drawn. The variation of air temperature at each station is so zigzagged that each *temperature curve* in Figs. 5 and 6 is drawn in using the smoothed variation of 5-day mean air temperature by the method of running average.

The dates of the first ice formation at Okhotsk on Siberian coast and at the six coastal stations in Sakhalin were announced by the Soviet Union's broadcasting of Synoptic ice state as Nov. 5 at Okhotsk, Nov. 28 at the Cape of Elizabeti, Nov. 29 at St. 32059 about whose place-name the author has no knowledge, Dec. 6 at the Cape of Kitashiretoko (Terpeniya), Dec. 7 at the Cape of Airō (Svobodnyj), and Dec. 29 at the Cape of Nakashiretoko (Aniva), all in 1960 as seen in Table 2. Though the pronounced date of the first ice formation at the Cape of Airō is Dec. 7, 1960 as mentioned above, the author uses the date of Dec. 15, 1960 for computing the degree days of frost, because no ice was observed there during four days succeeding to Dec. 11 as understood in the Table and then the date of Dec. 7 seems to have less significance in the present computation. Similarly, though the first ice formed in a corner of Monbetsu Harbor on Dec. 21, 1960, the date of the first ice formation must be pointed at Jan. 3, 1961 in the present computation, because the ice slush first formed in the outside of the harbor on this date as seen in the Table.

Using the above-explained necessary data, the t-θ diagrams in Figs. 5 and 6 are composed for computing the ice growth during southward drifts along the assumed drifting route illustrated in the inset chart of Table 1. In these diagrams each undulating thick and solid line represents the *temperature curve* at each coastal station, and each undulating thick and broken line which is made by interporation represents the one on the parallel of 48°N or 50°N. The dates of the first ice formation at these locations are shown in the upper scale, as f_E at

Table 2. Ice informations at the coastal stations from the Cape of Elizabeti, at the northern tip of Sakhalin, to Monbetsu in Hokkaido in the early ice season of 1960–'61. Drifting directions are presented by small arrows, showing the southward drifts by downward pointing arrows and the like.

Date	Cape of Elizabeti			Station 32059			C. Kitashiretoko			C. Airō			C. Nakashiretoko			Monbetsu	
1960 Nov. 28	6	Sl															
29	8	Sl	→	10	Sd	↓											
30	8	Sl		10	Sd	↓											
Dec. 1	9	Sl	↙	10	Sd	↓											
2	×	×		10	Sd	↓											
3	10	P		10	Sd	↓											
4	×	×		×	×												
5	×	×		10	Sd	↓											
6	10	Y,Ck	→	10	×	↓	7	Sd									
7	10	Y,Ck	→	10	Sd		6	Sd	↙	10	Sl^{K}						
8	10	W_1,Ck		10	R,Cs		10	R	↓	9	P						
9	10	W_1,Ck		×	×		6	P		5	P						
10	10	W_1,Ck	→	10	R,Cs		10	Sl^{K}		5	P,Fv						
11	×	×		10	R,Cs		10	P	↙	0	–						
12	10	W_1,Ck	←	×	×		10	R	↙	0	–						
13	×	×		10	R,Cs	↓	×	×		0	–						
14	×	×		10	Sd		9	Sl		0	–						
15	9	W_2,Ck	→	10	R,Cs	↓	8	Sd		9	Sl						
16	10	W_1,Ck		10	R,K		10	Sd		9	Sl						
17	×	×		10	R,Ck		8	P	↓	10	P,N						
18	9	W_2,Ck		10	R,Cs	↓	9	Y	↓	×	×						
19	×	×		10	R,Cs		10	Y,Cs	↓	8	P						
20	9	W_2,Ck	↖	×	×		×	×		×	×						
21	10	W_1,Ck		10	W_1,Ck		8	Y,Cs	↙	<1	P						
22	10	W_1,Ck		10	W_1,Ck		8	Y,Cs	↙	7	P						
23	10	W_2,Ck	→	10	Y,Cs		8	Y,Cs	↙	10	P						
24	×	×		×	×		×	×		×	×						
25	×	×		×	×		×	×		×	×						
26	10	W_2,Ck	→	10	Y,Ck		9	Y,Cs	↓	10	W_1,Ck						
27	<1	W_2,Ck	→	10	P	↓	10	Sd		10	W_1,K						
28	×	×		10	Sl^{K}	↓	9	Sd		10	R,K						
29	×	×		<1	Sl^{K}	↓	0	–		10	Sd		1~2	Sl			
30	×	×		×	×		5	Y,Cs		9	W_1,Cs		1~2	Sl			
31	10	W_2,Ck		×	×					10	W_1,Cs		4	Ck			
1961 Jan. 1	10	W_2,Ck		10	R,Cu					10	W_1,Cs		×	×		0	–
2	10	W_2,Ck	←	10	W_1,Ck	↓	10	Y,Cs	↓	9	Cb		×	×		0	–
3	10	W_2,Ck		10	W_1,Ck		10	W_1,Cs	↓	10	W_1,Cs		10	Sl,N		8	Sl
4	6	W_2,Ck		10	W_1,Ck		10	W_1,Cs	↙	10	W_1,Cs		10	Sl,N		0	–
5	10	W_1,Cs		10	W_1,Fa		×	×		10	W_1,Ck		×	×		0	–



the Cape of Elizabeti, f_{59} at St. 32059, ··· and f_M at Monbetsu. Their corresponding air temperatures are plotted on each *temperature curve*, as $\mathbf{F}_E$ at the Cape of Elizabeti, $\mathbf{F}_{59}$ at St. 32059, $\mathbf{F}_K$ at the Cape of Kitashiretoko, and so on, and then the *first ice formation curves* of $\mathbf{F}_E-\mathbf{F}_{59}$. $\mathbf{F}_{59}-\mathbf{F}_K-\mathbf{F}_A-\mathbf{F}_N-\mathbf{F}_M$ are made as the thick chain curves by connecting them. The *ice-developing domain* in this case occupies the right-hand and lower side of the curve.

Now, the first drift-ice in the winter of 1960-'61 was observed by an aircraft off Monbetsu on Dec. 23, 1960. The date is shown by a small arrow in the upper scale of the diagram of Fig. 5. From the point **M** representing the air

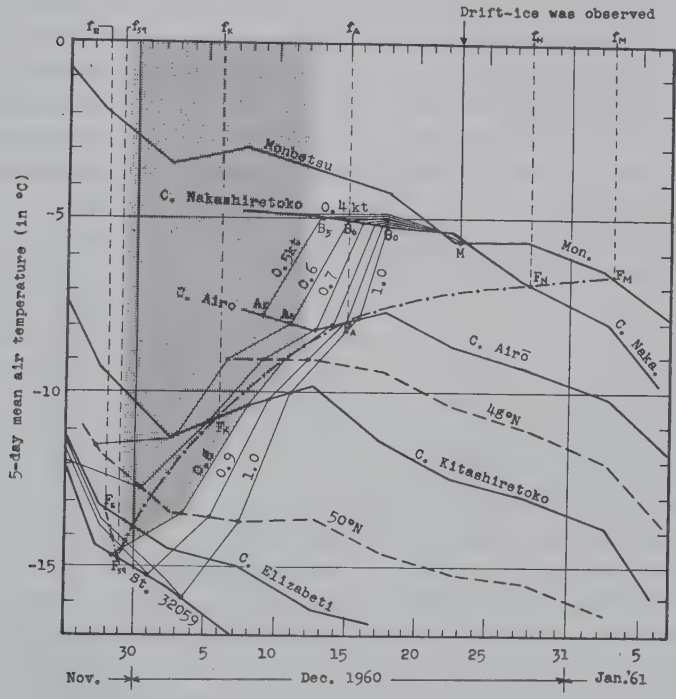


Fig. 5. Time-temperature diagram computing the amounts of degree days of frost acted on the drift-ice actually observed off the coast near Monbetsu on Dec. 23, 1960. Each undulating thick and solid line represents the variation of air temperature (5-day mean) at each station, and two undulating thick and broken lines for 48°N and 50°N parallels are made by interporation. The date of the first ice formation at each station is given by a downward pointing small arrow on the upper scale, namely, f_M at Monbetsu, f_N at the Cape of Nakashiretoko, f_A at the Cape of Airō, and so on. Then, the chain curves of $\mathbf{F}_M$—$\mathbf{F}_N$—$\mathbf{F}_A$—$\mathbf{F}_K$—$\mathbf{F}_{59}$ and of $\mathbf{F}_{59}$—$\mathbf{F}_E$ are the *first ice formation curves*. Thin solid undulating lines, which are called here the *drifting curves*, starting from the point **M** on the temperature curve at Monbetsu represent the drifting conditions corresponding to each given speed of drift. Thus, for instance, the shaded area gives the degree days of frost acting on the ice in its developing stage in the case of drifting speed 0.8 kt.

temperature at Monbetsu on Dec. 23, 1960, seven *drifting curves* corresponding to seven given drifting speeds of 0.4 to 1.0 kt run towards the *temperature curve* of the Cape of Nakashiretoko and intersect with it at the points $\mathbf{N}_1$ to $\mathbf{N}_7$, respectively. These curves are made by such way that the point $\mathbf{N}_1$ of the

drift with 0.4 kt, for instance, is fixed at the corresponding point to the date of Dec. 16, 1960 on the *temperature curve* of the Cape of Nakashiretoko, because the ice in question is to have passed through off the Cape 12 days before the date of its arrival at Monbetsu, i. e., Dec. 23, 1960 as presented in Table 1. Then, each curve runs towards the *temperature curve* of the Cape of Airō from the point $\mathbf{N}_1$, $\mathbf{N}_2$,··· or $\mathbf{N}_7$. Thus, each *drifting curve* successively extends to the *temperature curves* of 48°N parallel, of the Cape of Kitashiretoko, and so on. As seen in the diagram, the *drifting curves* of the given speeds slower than 0.8 kt lie in the outside of the *ice-developing domain*, whereas the ones of 0.8 kt, 0.9 kt and 1.0 kt intersect with the *first ice formation curve* (the thick chain curve) in the vicinity of the Cape of Airō and then run into the *ice-developing domain*. That means that the drift-ice in question ought to have drifted southward towards Monbetsu at a speed of 0.8 kt or faster. The *drifting curve* of 0.8 kt again intersects with the *first ice formation curve* near St. 32059 on Nov 29, and then enters into the outside of the *ice developing domain*. Thence, the thickness of the ice drifting with a speed of 0.8 kt grows in accordance with the amount of degree days of frost represented by the shaded area on the diagram of Fig. 5, which amount is measured at 175 deg·days. And the *drifting curves* of 0.9 and 1.0 kt intersect again the *first ice formation curve* between St. 32059 and the Cape of Elizabeti on Nov. 28. Thus, the amount of degree days of frost acting on the ice drifting with the speed of 0.9 or 1.0 kt is measured at 206 or 238 deg·days, respectively. Several formulas of transforming the amount of degree days of frost to the corresponding ice thickness have been given by many researchers after STEFAN's first theoretical consideration on ice growth (1890), and some of them have been practically used for ice prognosis. N. N. ZUBOV (1945a) gave an experimentally reformed formula for the ice growth in the Arctic region in the form of

$$I^2+50I=8R\,,$$

where I is the ice thickness in cm and R the degree days of frost. In our country, T. FUKUTOMI and his collaborators (1950, 1958) studied the problem theoretically and also formulated experimentally for newly formed ice off the Okhotsk Sea side coast of Hokkaido as

$$I^2=4.4\,R\,.$$

Though these two formulas, the former for the Arctic region and the latter for the

southwestern Okhotsk Sea, slightly differ from each other, we can estimate approximate thicknesses of drifting ice off the coast. A couple of curves presented in the right-hand in Fig. 7 are the ice thicknesses expected for the drift-ice observed by an aircraft off the coast neat Monbetsu on Dec. 23, 1960, which are transformed from the above-measured amouns of degree days of frost using ZUBOV's formula (broken curve) and FUKUTOMI's (solid curve). When a south-

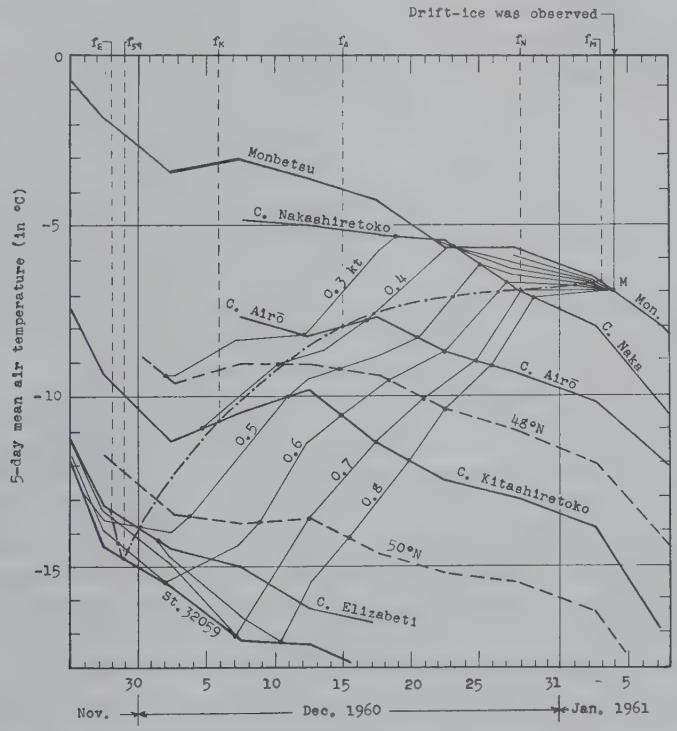


Fig. 6. Time-temperature diagram for computing the amount of degree days of frost acted on the drift-ice of 30–50 cm in thickness actually observed off the coast near Monbetsu on Jan. 4, 1961.

ward drifting speed is assumed as slower than 0.8 kt, the ice thickness is expected at zero as seen on the curves, in other words, such drift is impossible for the ice practically observed. Whereas, assuming the speeds between 0.8 and 1.0 kt for the ice's drift, the ice is to have developed at 20–30 cm in thickness until it

arrived at the coast. Moreover, from the dates when the *drifting curves* of 0.8, 0.9 and 1.0 kt secondly intersect with the *first ice formation curve* in the diagram of Fig. 5, the formation dates and the locations where the ice was born and simultaneously started on its southward drift are assumble as marked on the curves in Fig. 7. Thus, we can reasonably estimate for the ice in question that it ought to have been born near St. 32059 on about Nov. 29, 1960 when the drifting speed is assumed at 0.8 kt, and that in the sea region between St. 32059 and the Cape of Elizabeti on about Nov. 28, 1960 when 0.9 or 1.0 kt.

Similar estimation can be made by the diagram in Fig. 6 for the drift-ice of 30–50 cm in thickness observed by a patrol ship about 17 km off the coast on Jan. 4, 1961. The *drifting curve* of speeds slower than 0.4 kt lie, in this case, in the outside of the *ice-developing domain* in the major parts of their drifting period, except for the shorter period during 3rd to 4th in January of 1961. On the contrary, the *drifting curve* of 0.4 kt runs in the *ice-developing domain* between the Cape of Airō and 48°N parallel in the period from about 10 th to 23rd in December of 1960, where $R_1=240$ deg·days is measured, and also off Monbetsu from 3rd to 4th in the succeeding January, where $R_2=50$ deg·days. Thence, the total amount of degree days of frost acted on the ice in question is summed up at $R=290$ deg·days, and then the corresponding ice thickness is transformed at 10.3 cm by ZUBOV's formula, or 18.5 cm by FUKUTOMI's. Similarly computed thicknesses expecting for each speed from 0 kt to 0.8 kt are given in Fig. 7 by a brokn curve transformed by ZUBOV's formula and by a solid curve by FUKUTOMI's, together with the marks showing each assumed origin and formation date. These curves tell that, an ice of several centimeters in thickness drifting off Monbetsu on Jan. 4, 1961, whose existence is actually expectable, ought to have newly formed there on the preceding day and been drifting with a speed slower than 0.4 kt, and that the one of 10–20 cm in thickness is expected to have been born in a northern area of about 48°N parallel on about Dec. 10, 1960 and drifting with an average speed of about 0.4 kt, thus that the thicker is the observed drift-ice, the farther northern area out to be assumed as its origin and the earlier season as its formation date and moreover the faster as its southward drifting speed. Since the thickness were actually observed at 30–50 cm, the drift-ice in question is to have been born in the sea region east off northern Sakhalin north of about 52 N parallel at about the end of November in 1960, and come towards the coast of Hokkaido with an average speed of 0.6 kt

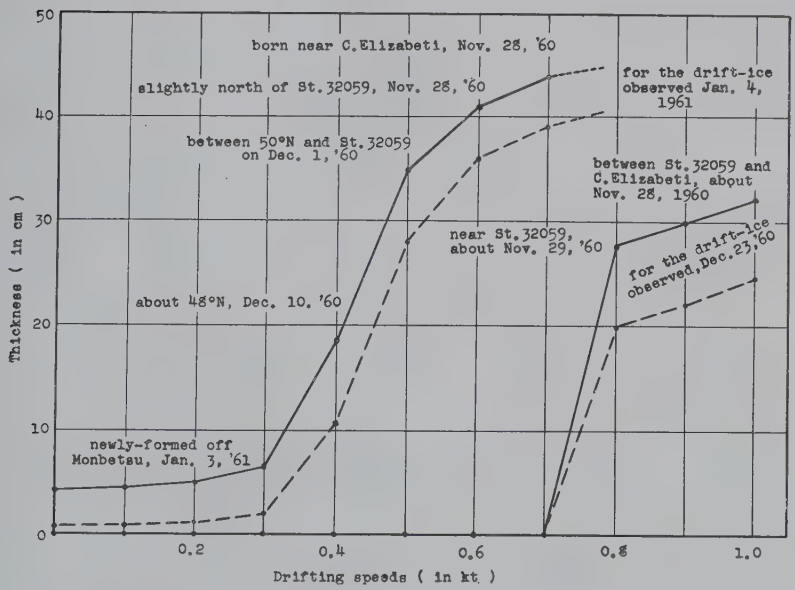


Fig. 7. Thicknesses of the drift-ices for the given drifting speeds from 0 kt to 1.0 kt computed by the diagrams of Figs. 5 and 6, with their estimated origins and formation dates marked. The solid curves are made by transformation due to FUKUTOMI'S formula from measured amounts of degree days of frost, and the broken ones by ZUBOV'S formula. The couple of curves in the right-hand is for the drift-ice observed off Monbetsu on Dec. 23, 1960, and the one in the left-hand is for the one on Jan. 4, 1961. From these curves it may be concluded that the major part of early drift-ice off the coast of Hokkaido ought to have been born off northern Sakhalin at about the end of November, at least in 1960, and drifted southward with an average speed faster than 0.6 kt.

or faster, maybe in a range of 0.6–0.8 kt.

4. Discussion

Now, the present estimation is based on an assumed drifting route illustrated in the inset chart of Table 1. If this assumption were not true in the actual drifting route, how would be the above-described feature of the ice's drift in fault? First, when the major part of drif-ice appearing off the coast of Hokkaido is assumed coming from Taraika (Terpeniya) Bay located just west of the Cape of Kitashiretoko, the time-temperature diagrams in Figs. 5 and 6 say that the ice should be thought to have been born in considerably earlier season than the

end of November in 1960 and also drifted with a very faster speed than 1.0 kt after staying there till the end of November. But such origin and drifting speed are impossible for the drift-ice in question because the actual date of the first ice formation at the Cape of Kitashiretoko was Dec. 7 in the year. Secondly, when the ice is assumed coming from an area far east of the assumed drifting route, the diagrams again call upon the ice in question an impossibly earlier date of formation and an unpractically faster speed of drift. From these considerations the assumed southward drifting route of ice along the east coast of Sakhalin is likely true without so large fault. Thence, it can be reasonably said that the major part of the drift-ice appearing off the coast of Hokkaido ought to have been born in the area east off northern Sakhalin and drifted southward towards Hokkaido along the above-assumed drifting route with an average speed in a range of 0.6 to 1.0 kt.

Such southward drift may be easily understood as being induced mainly or partly by the monsoon-like northerly wind which persists from November to the succeeding March. Three sets of wind-induced speeds of ice drift presented on the 4th, 5th and 6th lines of Table 3 are computed from an isobar pattern of the monthly mean surface pressures in December of 1960, for the three locations off the Cape of Elizabeti (at about 55°N), east off middle Sakhalin (about 50°N) and off Hokkaido (about 45°N), all along the above-described drifting route. In the Table, the distances of isobar-interval of 2 mb at these three locations are given on the 2nd lines, the wind speeds on sea surface on the 3rd line

Table 3. Speeds of wind-induced ice drift estimated from a chart of the monthly mean snrface pressures in December of 1960, where k is the wind factor.

Location along the assumed drifting route		Off C. of Elizabeti	East off middle Sakhalin (about 50°N)	Off Hokkaido (about 45°N)
Interval of 2 mb (in scale of latitude)		1.6°	1.5	2.0
Wind speed on sea surface = (geostrophic wind) × 3/4		4.3m/sec	4.5	3.5
Wind-induced drift (in speed)	by Zubov's drift	0.1$_+$kt	0.1$_+$	0.1
	by the linear drift, when k=0.02	0.2$_-$kt	0.2$_-$	0.15
	when k=0.04	0.3$_+$kt	0.35	0.3$_-$

that have been computed in multiplying the geostrophic wind by a factor of 3/4 (K. TAKAHASHI, 1958). On the 4th line of the Table are given rather slow speeds by Zubov's isobar-drift theory (1946 b), in which the wind-induced drift is expected as occurring along an isobar with a speed of V (in km/month) given by the formula of $V=1300\,dp/dx$, where dp/dx is the atmospheric pressure gradient (in mb/km). The amounts of wind-induced drift presented on the 5th and 6th lines of the Table are computed by an approximate formla of $v=kW$, where v is the speed of wind-induced drift, W the wind speed on sea surface (on the 3rd line) and k the wind factor. As the reasonable amount of k is considered 0.02 or so for ice drift off Hokkaido (WATANABE, 1963 b), the wind-induced component of the above-estimated southward ice drift is expected as 0.15—0.2 kt (on the 5th line of the Table), or about 0.2 kt in average. And it does not seem to exceed about 0.3 kt in average along the drifting route, even if k is assumed at 0.04 as on the 6th line of the Table, nearly its maximum amount for such long drifting route closely along the coast.

Thence, the excess of the above-estimated southward ice drift of 0.6—1.0 kt over the wind-induced drift of 0.2–0.3 kt, both in average speed, may suggest the existence of a southward flow of sea current, as actually has been computed at 0.7 and 0.3 kt from several observed velocities of drifting ices off the Cape of Notoro in February of 1957 and 1959, respectively (WATANABE, 1963 b). Referring to this southward directed sea current, a study on the sudden reinforcement of the East Sakhalin Current occurring in late fall or early winter will be presented in the succeeding report of the present thesis (WATANABE, 1963 c).

Acknowledgment: Sincere gratitude should be expressed to Dr. Kazuhiko TERADA of the Japan Meteorological Agency and Mr. Zen'ichi YASUI of the Hakodate Marine Observatory for their continuous encouragements throughout the present work.

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The Oceanographical Magazine
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On the Reinforcement of the East Sakhalin Current preceding to the Sea Ice Season off the Coast of Hokkaido

— Study on Sea Ice in the Okhotsk Sea (IV) —

By

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Abstract: An existence of southward flow of sea current has been suggested for the area east off Sakhalin and off Hokkaido in the Okhotsk Sea in the preceding paper on the present thesis (WATANABE, 1963c). Here in the present paper is discussed a reinforcement of the East Sakhalin Current occurring in late fall or early winter. First, several sets of observational data on sea conditions collected off Hokkaido in 1958 are studied in such conclusion that a southward flow of low saline water is suddenly intensified off Hokkaido during November to December, then a conspicuous reinforcement of the East Sakhalin Current is discussed. And finally, the current is shown as a carrier of the drift-ice and of the water forming new ice, from the northwestern Okhotsk Sea towards the area off Hokkaido.

1. Introduction

The drifting route of ice in the area off the Okhotsk Sea side coast of Hokkaido shown by the characteristic patterns of sea ice distribution (WATANABE, 1963a), and several groups of measured velocities of drift-ice there together with separately computed velocities of current-induced drift of ice, i. e. drifting velocities independent of local wind (WATANABE, 1963 b) suggest a southward drifting route from the east offing of northern Sakhalin along the coast of the island toward Hokkaido. Then the drifting speed of 0.6—1.0 kt of the early drift-ice along the assumed route has been estimated by a diagrammatic method from the arrival dates and the observed thickness of drift-ices off the coast of Hokkaido (WATANABE, 1963c).

Such southward drift of ice with notably high speed as 0.6—1.0 kt may lead an idea that the drift is induced not only by the northwesterly wind of monsoon type but also by an southward flow of sea current as mentioned in the preceding paper on the present thesis (WATANABE, 1963c), though such sea current has not

hitherto been recognized in the recent oceanographical investigations (K. KAJIURA, 1949, T. TABATA, 1952, and Y. AKIBA and others, 1959). Now the author who has reported a preliminary study on the sudden reinforcement of a southward flow of low saline water off Hokkaido in the Okhotsk Sea in early winter (WATANABE, 1959) has been able to reasonably confirm that the East Sakhalin Current runs along only the coast of northern half part of Sakhalin in warmer season, whereas in cooler season it develops to run throughout the whole offing east of the island in consequence of a sudden reinforcement of the current occurring during late fall or early winter.

2. *Seasonal variation of surface chlorinity off the Okhotsk Sea side coast of Hokkaido in 1958.*

In order to study the profile of seasonal variation of sea conditions off the coast of Hokkaido in the Okhotsk Sea, Figs. 1a, 1b, 1c and 1d are presented for the surface chlorinity distributions in August, October, November and December of 1958, in which year eight oceanographic observation cruises were successively made in the sea region in question during April to the end of December by patrol ships of the First Regional Maritime Headquarters, and a research ship of the Hokkaido Regional Fisheries Research Laboratory, and the observation ship of the Hakodate Marine Observatory. In August (Fig. 1a) the comparatively high saline water of more than 18.40 ‰ in chlorinity distributed on the inshore area of Hokkaido coast where the Sōya Warm Current, an end flow of the Tsushima Warm Current, runs southeastwards closely along the coast. In contrast to this, the low saline water of less than 18.00 ‰ widely occupied the offshore area with two tongue-like spreads of lower saline water than 17.60 ‰ in chlorinity. The only systematic sea current in this area is the Sōya warm current referred above of maximum speeds of 2 kt or so, whereas no systematic current has been observed in the offshore area covered by low saline water in the warmer season.

As the season advanced through October to November, the low saline water in the shoreward tongue gradually spreaded in area and deepened in lowness of chlorinity, while the Sōya Warm Current was weakened in width as illustrated in Fig. 1b (October and 1c November). Then in the end of December, the low saline water with the extremely low chlorinity less than 17.20 ‰ spreaded southwards directly to the coast near Ōmu and Monbetsu, cutting off the southeast-

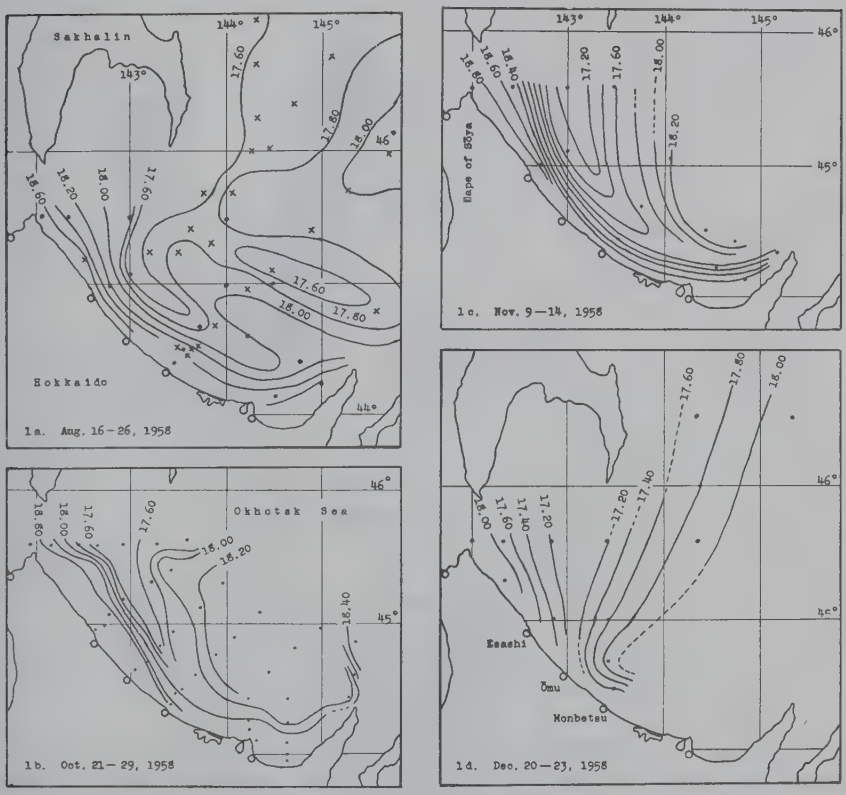

Fig. 1a, 1b, 1c and 1d. Surface chlorinity distributions in Aug. (1a), Oct. (1b), Nov. (1c) and Dec. (1d).

ward flow of the Sōya Warm Current at about Esashi as clearly seen in Fig. 1d. This spread of the low saline water was confined to the surface layer to about 50 m as shown by the vertical section of chlorinity distribution on the east-west observation line set from near the tip of the Cape of Sōya in Fig. 2a (August), 2c (November) and 2d (December)——Fig. 2b for October is omitted here. Such development of the low saline water during from warmer to cooler seasons is more clearly shown in a T-Cl diagram in Fig. 3. In this figure are picked up the stations A_1 (observed on Aug. 22) A_2 (Oct. 24), A_3 (Nov. 11) and A_4 (Dec. 20) located just south off the Cape of Nakashiretoko or Aniva, one of the southern

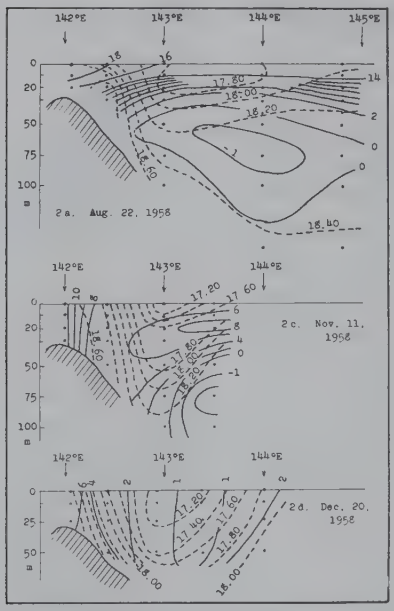

Fig. 2a, 2c and 2d. Vertical section of chlorinity distribution along the east-west observation line set from near the Cape of Söya, in Aug. (2a), Nov. (2c) and Dec. (2d).

tips of Sakhalin. The chlorinity in the layers of 0 m and 10 m was about 17.80 ‰ in summer (St. A_1), dropped to about 17.60 ‰ in November (St. A_3) after slight decreases in October (St. A_2), then showed an extremely low amount of 17.20 ‰ in late December (St. A_4) with low temperatures of 0.5°−1°C. Besides, in December the layers at 25 m and 50 m were in lower chlorinity than at the layers of 0 m and 10 m in summer and fall. This drop in chlorinity shows that the low saline surface water was suddenly reinforced in November and December. And, considering on the fact that there is no source of such low saline water in the area in question and its vicinity the water has to be assumed flowing southward along the east coast of southern Sakhalin.

In December the water temperature was nearly so uniform both in the horizontal and vertical distributions excepting in the area of the Soya Warm Current as seen in Fig. 1d and 2d, that the density distribution is determined mainly

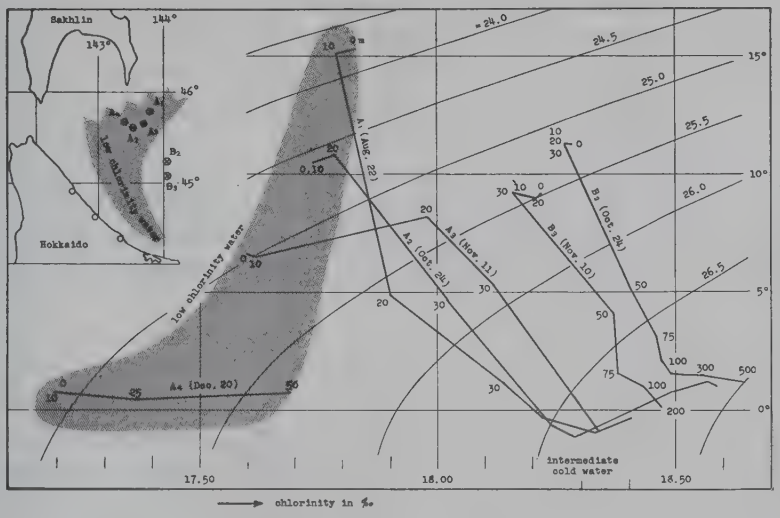

Fig. 3. T-Cl diagram for the low saline water.

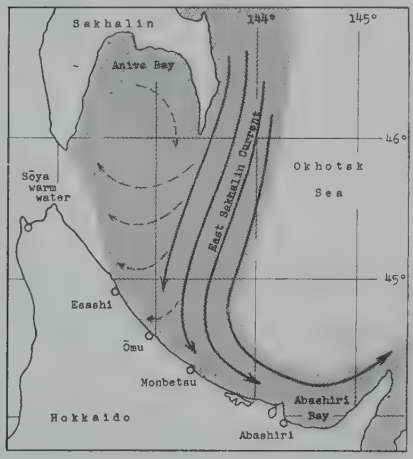

Fig. 4. A schematic representation of the flowing of the low saline water. This flow is concluded as an end flow of the East Sakhalin Current in the later section.

by the chlorinity distribution. In other words, we can roughly have an image of flowing system of the low saline water merely from a surface chlorinity distribution like Fig. 1d. Thence, a southward flow of the low saline surface water in winter season is presumable for the area in question as the one schematiccally represented in Fig. 4 in corresponding to the surface distribution of chlorinity presented in Fig. 1d. Namely, the low saline water coming from the north is considered to run nearly southward off the Cape of Nakashiretoko towards the coast of Hokkaido, then to flow southeast-and east-ward closely along the coast. This profile of current system just coincides with the drifting route of ice described in the preceding papers (WATANABE, 1963a, 1963b).

3. Sudden reinforcement of the East Sakhalin Current

Before describing a consideration in the present item, it may be better to continue a more short discussion about the development of the low saline water as in the following lines. In Fig. 5 the amounts of surface chlorinity are plotted

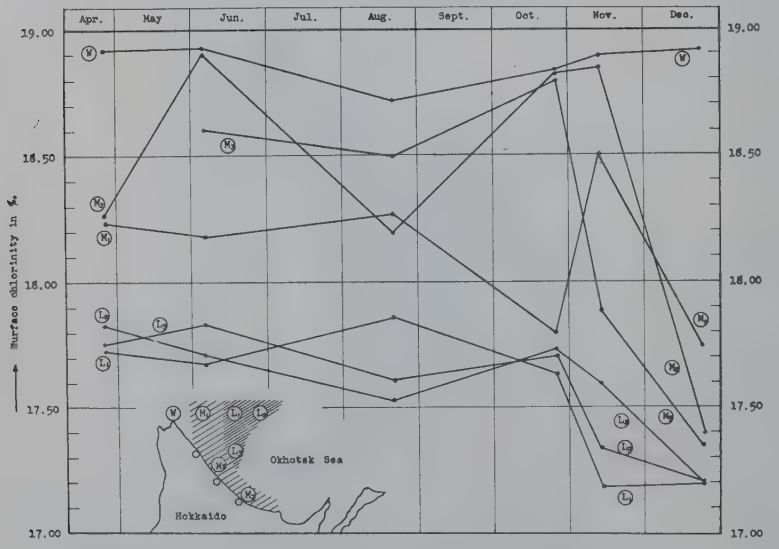

Fig. 5. Seasonal variation of surface chlorinity observed in 1958, in the Sōya Warm Current (**W**), the low saline water ($\mathbf{L}_1$, $\mathbf{L}_2$, $\mathbf{L}_3$) and the mixing area ($\mathbf{M}_1$, $\mathbf{M}_2$, $\mathbf{M}_3$) of the former two.

for each location shown in the inset chart from April to late December, basing again on the observational data in 1958. The high values and less variability of the surface chlorinity at **W** closely near the Cape of Sōya show that the area near the cape was washed by the Sōya Warm Current throughout all season. While, at $\mathbf{L}_1$, $\mathbf{L}_2$ and $\mathbf{L}_3$ in the flowing area of the low saline water the surface chlorinities of 17.60 to 17.80 ‰ continued from April to about the end of October with less variations, then after suddenly decreasing in November, further decreased to about 17.20 ‰ in December. In the intermediate area at $\mathbf{M}_1$, $\mathbf{M}_2$ and $\mathbf{M}_3$ between these two contrasting regions, the amounts of surface chlorinities lie between the ones in the Sōya Warm Current and in the low saline water, but similarly droped during the middle of November to the end of December. This fact means that the southward flow of the low saline water spreaded towards the shoreward area including $\mathbf{M}_1$, $\mathbf{M}_2$ and $\mathbf{M}_3$, then began to wash the coast near Esashi, Ōmu and Monbetsu instead of the Sōya Warm Curreat. Accordingly, data of the water density observed at each shore station are expected showing this sudden approach of the low saline water at that period. In Fig. 6 the amounts of σ_{15}

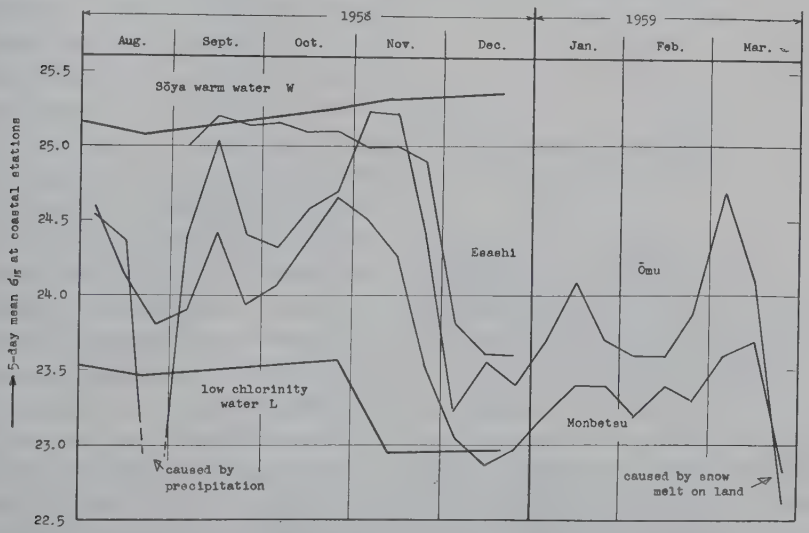

Fig. 6. Seasonal variations of 5-day mean σ_{15} at three shore stations during from Aug. in 1958 to Mar. in 1959. The densities in the Sōya Warm Current (**W**) and the low saline water (**L**) computed from the chlorinities presented in Fig. 5 are plotted for comparision.

at Esashi, Ōmu and Monbetsu are plotted for the period from August of 1958 to March of 1959 and in the same time the ones in the Sōya Warm Current (**W**) and in the low saline water (**L**) based on the former figure are presented for comparision. The amounts of σ_{15} at the stations vividly show their sudden and deep drops at the end of November and in the beginning of December in 1958.

Though the above descriptions about the reinforcement of the low saline water are based on the observational data only in 1958, this characteristic phenomenon has been usually occurred every early winter as illustrated in Fig. 7. The figure presents the seasonal variations of σ_{15} at the shore stations as separate 5-day means for 10-year period from 1951 to 1960 except Monbetsu where the one for 5-year period from 1957 to 1961, and again the ones in the Sōya Warm Current and in the area of the low saline water observed in 1958 for comparision. The mean σ_{15} at Wakkanai shows none of its drop in winter season showing that the Sōya Warm Current washes there throughout all the year. While, at the other stations deep drops of the mean σ_{15} occur during from the end of October to the beginning of December. Consequently, it can be concludingly said that a sudden reinforcement of the southward flow of the low saline water as illustrated in Fig. 4 occurs every year in late fall or early winter off the coast of Hokkaido in the Okhotsk Sea.

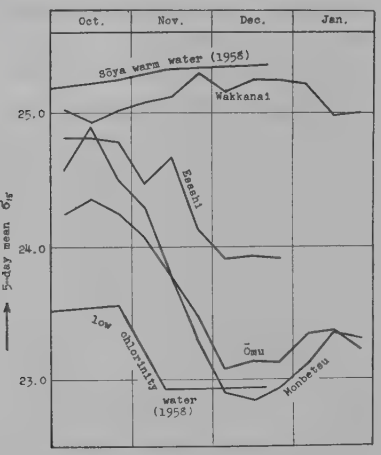

Fig. 7. Sudden drop of mean σ_{15} at Esashi, Ōmu and Monbetsu. The σ_{15} at Esashi and Ōmu are separate 5-day means for 10-year period from 1951 to 1960, and the one at Monbetsu for 5-year period from 1957 to 1961.

Then, where comes this low saline water from? An extremely low saline water of 16.20‰ in chlorinity is seen in the sea-region east of the northern Sakhalin in the chart of surface chlorinity distribution observed in July of 1958 by the training ship "Hokusei Maru" of the Faculty of Fisheries, Hokkaido University (Fig. 8). From this region an area of low saline water less than 17.60‰ spreads along northern Sakhalin with a tongue-like pattern towards the middle Kurile Islands. Though the existence of a southward flow of this

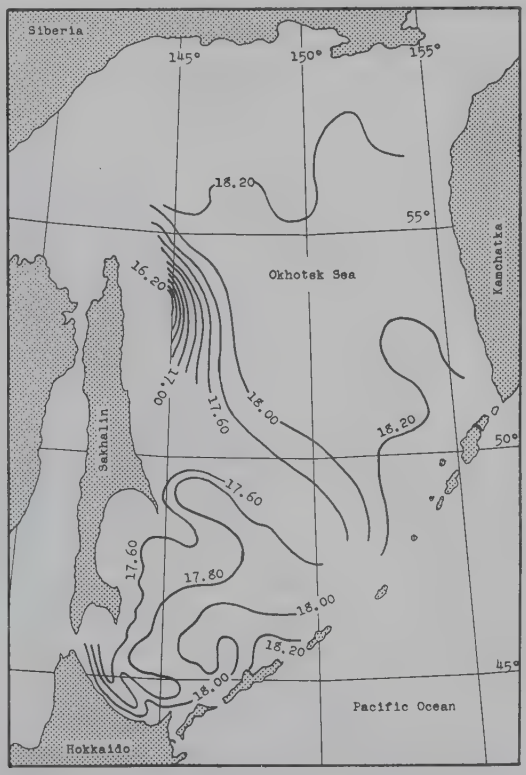

Fig. 8. Distribution of surface chlorinity in the Okhotsk Sea in Aug. of 1958.

extremely low saline water along northern Sakhalin, namely the East Sakhalin Current, has been shown by Y. AKIBA and his collaborators (1959) using the Hokusei Maru's data, a weak northward current has been found by them in the region east of central Sakhalin by their dynamical topography computations. And their study has shown none of the southward flow off the east coast of southern Sakhalin. Bisides, all other investigations made recently on the sea conditions in the Okhotsk Sea equally don't have recognized the existence of a southward flow, i. e. an end flow of the East Sakhalin Current, in the southern region of the sea (K. KAJIURA, 1949, T. TABATA, 1959, and J. SUGIURA, 1958). All these studies are the ones related to the sea conditions only in warmer season based on the data collected during from May to August, so that

the southward flow in cooler season has been missed hitherto, because of utterly lacking of winter data.

Now, there is a way of confirming the source of the above-described southward flow of the low saline water. Monthly mean precipitations at several necessary stations are presented in the following Table. Considering from the

Table 1. Monthly mean precipitations (in mm) at the coastal stations in the western side of the Okhotsk Sea.

Location \ Month	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Amur (along the Amur River)	159	91	60	34	20	6
Okhotsk (at about the northwestern corner of the Okhotsk Sea)	40	53	33	17	17	12
Shikuka, or Olekminsk (in central Sakhalin)	65	74	51	30	19	17
Ōdomari, or Korsakov (in southern Sakhalin)	58	61	52	24	4	3
Abashiri (in Hokkaido)	86	98	126	84	80	52

decreasing amounts of precipitation with season advance from summer to early winter at Abashiri in Hakkaido, Ōdomari (*Korsakov*) in southern Sakhalin, and Shikuka (Poronisk) in the central Sakhalin, it is made clear that the precipitation is not responsible to the sudden drop of σ_{15} of the low saline water, or the sudden reinforcement of the southward flow occurring in the region off the coast of Hokkaido in late fall or early winter as illustrated in Fig. 4. The rest only one possibility for the phenomenon is the reinforcement of the East Sakhalin Current during fall to winter which consisted of the coastal water mainly due to the one from the Amur River as recognizable in the Table. Thus, it is reasonably concluded that the East Sakhalin Current runs southward in the region east of the northern half part of Sakhalin as south as about the Kitashiretoko (Terpeniya) Peninsula, but in cooler season after fall runs through all the east offing of Sakhalin as south as the coast of Hokkaido by its somewhat strong reinforcement maybe due to the monsoon-like northwesterly wind. This is schematically illustrated in Fig. 9a and 9b, where the current system in warmer season is presumably drawn by combining the results of the above-referred investigations (K. Kagiura, 1949, T. Tabata, 1952, Y. Akiba and others, 1959) and Leonov's description (1960).

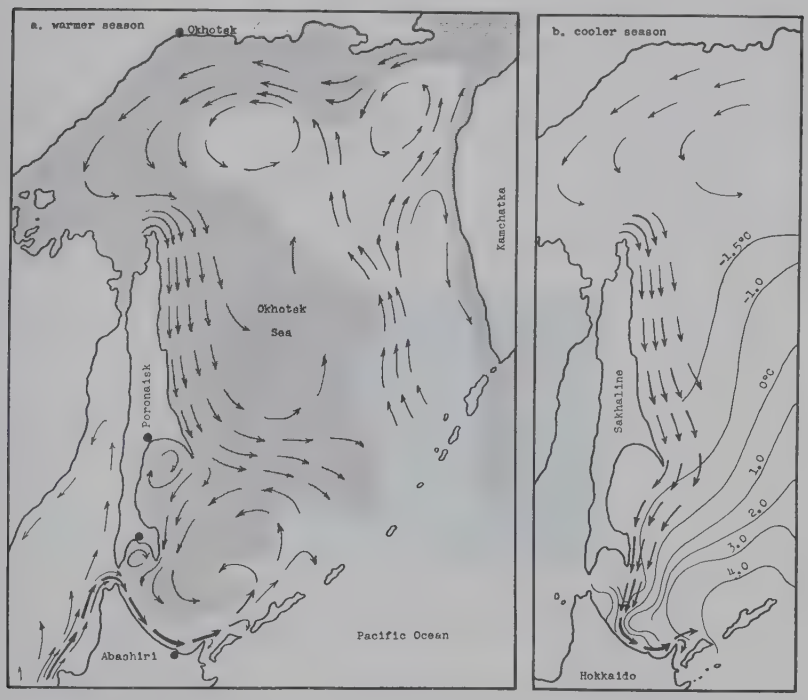

Fig. 9a, 9b. Estimated current systems in the Okhotsk Sea in warmer season (9a) and cooler season (9b). In Fig. 9a, the shaded area represents the region having a possibility of 50% in surface chlorinity of less than 18.00‰. And 5-day mean surface temperatures during Dec. 26–31, 1959 are drawn in Fig. 9b.

4. Carrier of the drift-ice and of the water forming new-ice off Hokkaido

As summarized in the first paper in the present thesis (WATANABE, 1963a), every winter occurs the coming of an enormous amount of drift-ice from north together with active formation and development of new ice to the sea-region off Hokkaido. As the drifting route of ice off Hokkaido is along the above-discussed end flow of the East Sakhalin Current presented in Figs. 4 and 9a, it can be reasonably said that the current is just the carrier of drift-ice, in other words, the current is considered carrying ice masses formed in the northern region of the Okhotsk Sea to the region off Hokkaido, the most southern region of the sea. Such southward drift of ice, in a scale from the northern to the most

southern region of the Okhotsk Sea has been studied in the preceding paper (WATANABE, 1963c). Besides, since a strong stratification exists in the surface layer of the current, the surface water tends to be easily cooled as low as its freezing temperature with less vertical mixing in mid-winter. This is the reason why very active ice formations occur everywhere in open waters among ice cover in the region off Hokkaido though it is located at such low latitudes between 42° and 45.5° N. Fig. 10 is presented for showing an aerial view of an icy stream newly formed in the Abashiri Bay.

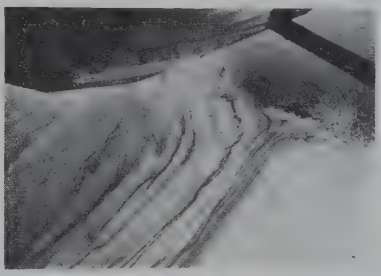

Fig. 10. Aerial view of an icy stream newly formed along the edge of an accumulated winter-ice mass (right-hand and lower side) in the Abashiri Bay, from an altitude of 6,000 ft on Feb. 12, 1959.

Then, it is expected that the period of the sudden drop of σ_{15} at each shore station may have a relation to the dates of the first ice formation and of the first drift-ice, the date of the first arrival of drift-ice at the coast. In Fig. 11 the daily σ_{15} at Monbetsu are plotted for the period from October to the succeeding January in the years from 1957 to 1962, with marks of small black arrows for the dates of the first drift-ice and white ones for the first ice formation there. In the winter of 1957—'58 the sudden drop of σ_{15} occurred on about Nov. 21, 1957 as marked by a shaded arrow, then the first ice formation and the first drift-ice followed on 2nd and 15th, respectively in January of 1958. And in the next winter, a very ice-poor winter, the occurrence of the σ_{15} drop was late by 4 days than in the preceding winter, then the arrival of the first drift-ice was correspondingly late by 5 days. Whereas in a fairly ice-rich winter of 1959—'60, the σ_{15} drop occurred on Nov. 19, 1959, then the first drift-ice appeared on Jan. 14. And in the winter of 1960—'61, the ice-strongest winter during recent years, the σ_{15} remarkably dropped early on Nov. 8, 1960, then the very

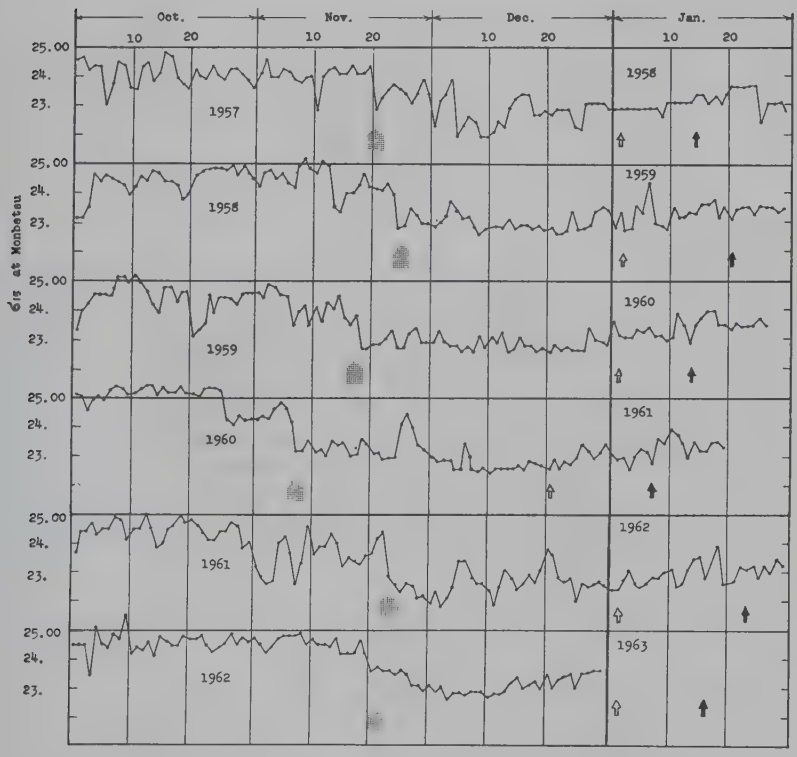

Fig. 11. Variation of daily σ_{15} at Monbetsu. The small black arrows point the dates of the first drift-ice, and the white ones the dates of the first ice formation. The shaded arrows show the periods of the sudden drops of σ_{15}.

early formation of the first new ice and the arrival of the first drift-ice followed on Dec. 21 in 1960 and Jan. 8 in 1961, respectively. As seen in this example, the relation between the period of the σ_{15} drop and the first days of ice formation or of drift-ice seems to be very useful for ice prognoses.

Aknowledgment: The author wishes to express his sincere thanks to Dr. Kazuhiko TERADA of the Japan Meteorological Agency and Mr. Zen'ichi YASUI of the Hakodate Marine Observatory.

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Note of the Japanese Expedition of Deep-Sea the Fifth Cruise, 1962 (JEDS-5)*

By

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Japan Meteorological Agency

The Japanese Expedition of Deep-Sea, the Fifth Cruise (JEDS-5) which had been planned by the Deep-Sea Research Committee (Chairman, K. WADATI), Japan Society for Promotion of Science, was carried out in May, 8 to 31 and in June, 8 to 30, 1962 on board the R/V Ryofu Maru (Captain, T. SUENAGA) of the Japan Meteorological Agency. In the former period, the project aimed mainly to hydrographical researches of the current pattern in the neighbourhood of the submarine plateau far east of Japan, and a few samplings of bottom sediment, deep-water plankton, benthos and so on were also carried out. In the later period, various kinds of physical, chemical, biological, geophysical and geological observations and samplings were carried out along the observation line of 34°N

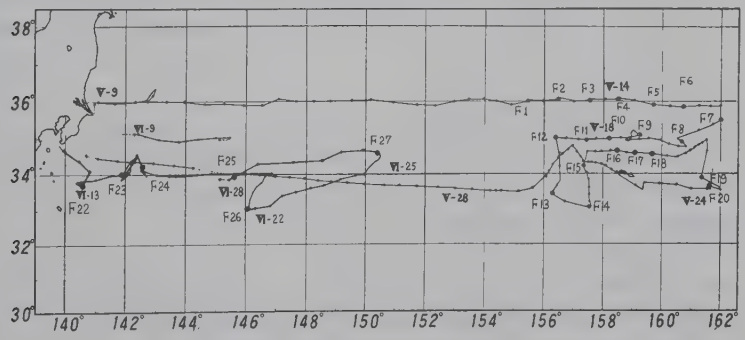

Fig. 1. Station and track chart of JEDS-5 cruise aboard R/V Ryofu Maru.
● Special station for deep-sea research
⊙ Hydrographical cast station
• BT station

* JEDS Contribution No. 46

latitude, from 141°E to 150°E longitude. The location of stations is summarized in Fig. 1.

Research members on board the Ryofu Maru

May, 8.～31.

Japan Meteorological Agency: J. Masuzawa (Phys. Ocean.), M. Yasui (Geophys.), H. Akamatsu (Phys. Ocean.), T. Nakai (Phys. Ocean.), I. Kashiwa (Phys. Ocean.), T. Akiyama (Chemistry), Y. Kawarada (Plankton)
Meteorological Research Institute: Y. Sugiura (Chemistry), Y. Sugimura (Chemistry)
Hakodate Marine Observatory: H. Iida (Phys. Ocean.)
Tokyo University: K. Hôrai (Geophys.)
Tokyo University of Education: K. Kobayashi (Geology)
Ochanomizu University: M. Horikoshi (Benthos)
Tohoku University: H. Mii (Geology)

June, 8.～30.

Japan Meteorological Agency: M. Yasui (Geophys.), H. Akamatsu (Phys. Ocean.), T. Sawara (Phys. Ocean.), S. Hasegawa (Phys. Ocean.), T. Nakai (Phys. Ocean.), K. Fujii (Phys. Ocean.), Y. Kawarada (Plankton)
Meteorological Research Institute: Y. Sugimura (Chemistry)
Hakodate Marine Observatory: M. Ohwada (Plankton)
Kobe Marine Observatory: H. Kitamura (Chemistry)
Nagasaki Marine Observatory: S. Fujita (Phys. Ocean.)
Hydrographic Office: T. Sato (Geology)
Tokyo University: K. Hôrai (Geophys.), Y. Kagami (Geology)
Tokyo University of Education: E. Wada (Chemistry)
Ochanomizu University: M. Horikoshi (Benthos)
Kyoto University: E. Harada (Biology)
Kyushu University. H. Mitsushio (Geology)
Physical & Chemical Research Institute: S. Watanabe (Phys. Ocean.), K. Kajiwara (Phys. Ocean.), M. Okazaki (Phys. Ocean.)

Station of observations and collections.

(1) Hydrographical casts
F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10}, F_{11}, F_{12}, F_{13}, F_{14}, F_{15}, F_{16}, F_{19}, F_{23}, F_{27}.

(2) Water sampling for special chemical analyses
F_{23}, F_{26}, F_{27}.

(3) Measurements of geothermal gradient
F_{20}, F_{23}, F_{24}, F_{25}.

(4) Bottom-core sampling
F_{18}, F_{25}, F_{27}.

(5) Sampling of deep-water plankton
F_{21}, F_{23}, F_{27}.

(6) Sampling of benthos and geological materials by beam trawl
F_{17}, F_{22}, F_{27}.

Besides, the surface-current measurements with GEK, BT observations and echo soundings were carried out underway.

Details of results in each branch shall be published in near future by other research members and shall be collected in the "Report of JEDS".

The Oceanographical Magazine
Vol. 14. No. 2, March 1963

Deep Current Measurements in the Cold Water Mass and Vicinity, the Enshū Nada Sea*

By

Tosio Nan'niti *Meteorological Research Institute*
Akira Watanabe *Meteorological Research Institute*
Hideo Akamatsu *Japan Meteorological Agency*
Toshisuke Nakai *Japan Meteorological Agency*

(Received January 23, 1963)

Abstract: The deep currents in the sea of Enshū-Nada were observed by means of neutral-buoyancy floats using four hydrophones, currents ranging 17.5 and less than 3 cm/sec have been measured, at depths 1000 and 2000 meters.

1. Listening arrangements

For the former observations, the two hydrophones were lowered to a depth of about 15 m from the bulwark of the ship along the keel line. Now more two hydrophones were suspended to the sea on the twin cable from the booms which were perpendicular to the both sides of the ship, respectively. The ends of booms were fixed to the each bulwark plate, and the other ones were suspended from the ship's mast. (Fig. 1) These lowered hydrophones were 30 m apart each other.

The differences in times of arrival of signals from the float at the each pair of two hydrophones were observed, in the directions of the keel or perpendicular lines which were selected by the switch.

By this better method, we can decide the positions of floats with more accuracy and less time for observations, further the ship's head does not need to fall away from the wind direction to depict a "figure-eight" polar diagram.

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* JEDS Contribution No. 43.

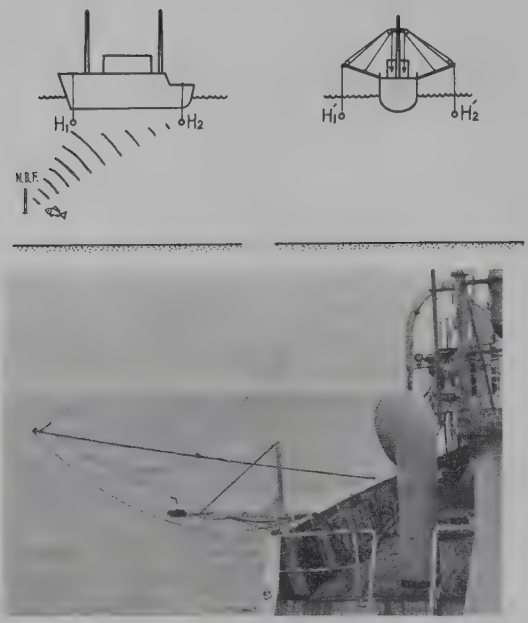

Fig. 1. Schematic diagram of booms, hydrophones and general view of left side boom.

An accuracy of bearings from Loran fixes of the ship's position seems to be about ±1.0 mile in the daylight and ±0.5 miles at night.

2. Observations

Contours of water temperature at a depth of 100 meters, the surface currents by G. E. K. and the positions of stations are also shown in Figs. 2 and 3.

The measurements were made on Ryōfū-Maru at the station 32°50′N, 138° 20′E shown in Fig. 2. On November 19–20, 1962, the positions of the float were plotted relative to the ship. (Fig. 4) The mean currents have been obtained by plotting the north-south and east-west components of displacement separately against time. (Fig. 5)

The mean current is 17.5 cm/sec, bearing 240° at a depth of 980 m, and the surface current by G. E. K. observation is about 1 kt bearing 140°.

As shown in Figs. 2 and 3, the station is in the cold water region, and the current direction by the float coincides with the one supposed by the contour

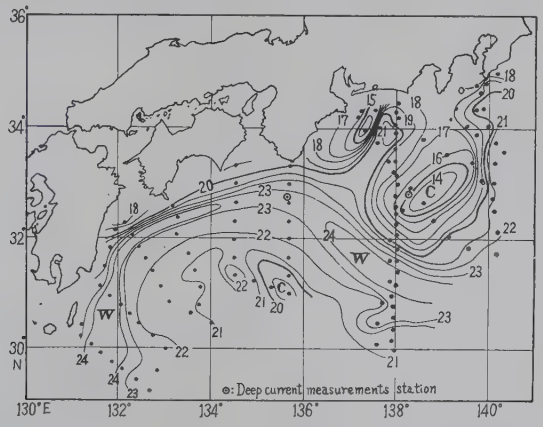

Fig. 2. Temperature (°C) at a depth of 100 meters and deep current measurements stations.

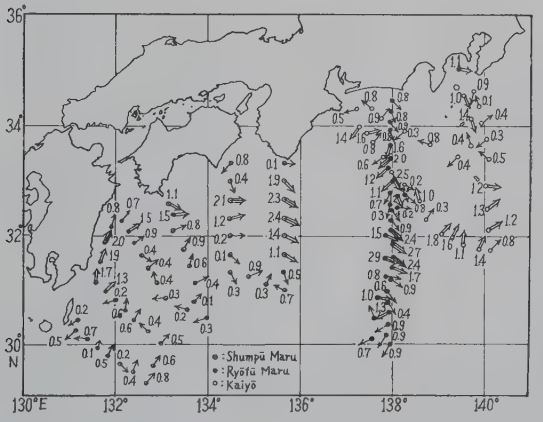

Fig. 3. Current measurements made with the G.E.K. by the research vessels Shumpū-Maru, Ryōfū-Maru and Kaiyō, the speed in knots are printed next to the arrows.

line of 100 m temperature, on the other hand, it does not coincide with the direction by the present G. E. K. observation. But, this surface current direction in the cold water region was so variable with time that they do not coincide with each other, for the following observations in Fig. 3 show the above

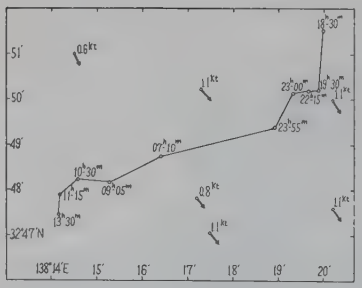

Fig. 4. Positions of float and surface currents, the speeds in knots.

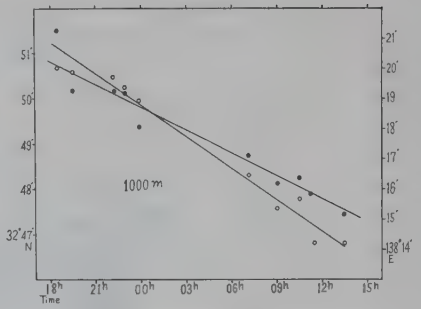

Fig. 5. Components of displacement of float plotted against time.
●: latitude ○: longitude

conclusion, which were made by the Kobe Marine Observatory, Japan Meteorological Agency and Hydrographic Office at the time interval of about 10 days, respectively.

On former another day, November 23, 1961, also the deep current measurements were done at 32°47′N, 135°38′E at the depth of 2000 m, though we could not have a definit current direction at bad weather conditions, but it seemed to be that the velocity of the layer must be less than 3 cm/sec.

At any rate, in the cold water region, the water flows in cyclonic swirl from the surface to the depth more than 1000 meters, the velocity decreases vertically from 1.0 to 0.35 kt; upwelling motion might be traced to the more than 1200 m deep, but we could not suppose that such a deep layer as 1000 m had a considerable cyclonic velocity 0.35 kt (NAN'NITI, 1957).

As mentioned above, the general flow has a velocity 1.5—2.0 kt at the surface, 0.06 kt or less at the 2000 m layer reasonably assuming that it has the same direction as the upper, which was also not expected that such a deep layer had a considerable velocity (NAN'NITI, ibid), but the former conclusion that the Kuroshio flows with cyclonic curvature around the cold water mountain according the BOLIN's equation is yet available. These vertical current profiles are approximately similar to the former results obtained in the Western North Pacific (NAN'NITI, 1962).

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The Oceanographical Magazine
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The General Account of the Plankton Survey on the Fifth Cruise of the Japanese Expedition of Deep Sea (JEDS-5)*

By

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Ryuzo Marumo *Japan Meteorological Agency*
Yutaka Kawarada *Japan Meteorological Agency*
Yuzo Komaki *University of Tokyo*

(Received January 28, 1963)

In June of 1962, the Fifth Cruise of the Japanese Expedition of Deep Sea (JEDS-5) was done by *Ryofu Maru* of the Japan Meteorological Angency along the latitude of 34°N. At two stations among the whole station on this cruise, i. e. station F_{23} and F_{27}, plankton collections were carried out. In this report, the authors confined themselves to give the general account on sampling method and the result of collections. Further detailed studies on collected animal groups will be done by specialists in each field taxonomically and ecologically in near future.

The net used on this cruise, as shown in Fig. 1, is a closing type. It is consisted of two parts, the upper and the lower. The upper part has a mouth ring with 130 cm in diameter and cylindrical coarse nylon cloth with 165 cm in side length. The lower one has a trunk ring with the same diameter as the mouth ring and the conical filtering part composed of coarse nylon cloth with 375 cm in length and bolting cloth with 140 cm in length. The aperture size of coarse nylon cloth and that of bolting cloth mentioned above is 3.0 mm and 0.33 mm respectively. The closing apparatus (Fig. 2) is originated from the Discovery's single action type (Kemp and Hardy, 1929).

The net was lowered in opened state (Fig. 1–A) down to the depth at which vertical haul should be begun. Considering the running speed of a messenger and the hauling speed of the net, the messenger was shot down so that it just met with the closing apparatus at the depth where the net was expected to close, while the net was hauling. When the messenger struck the trigger of

* JEDS Contribution No. 44

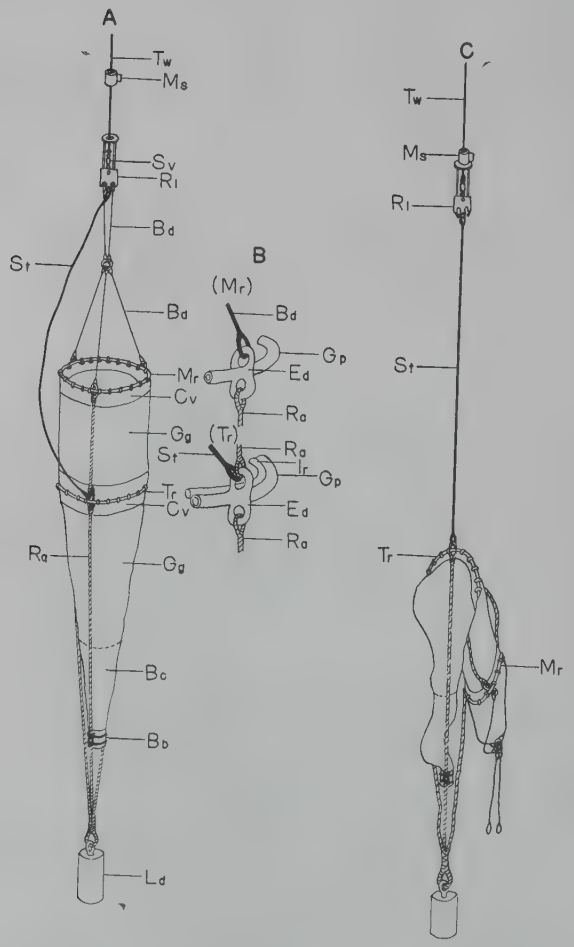

Fig. 1. 130-cm closing net, **A**; open position, **B**; mouth ring and trunk ring, **C**; closed position. Abbreviation **Bb**; bottom bucket, **Bc**; bolting cloth, **Bd**; bridle, **Cv**; canvas, **Ed**; double eyes, **Gg**; coarse nylon cloth; **Gp**; gas pipe, **Ir**; iron rod, **Ld**; lead, **Ms**; messenger, **Mr**; mouth ring, **Ra**; additional rope, **Rl**; release, **St**; trunk ring suspender, **Sv**; swivel, **Tr**; trunk ring, **Tw**; tapered wire.

Table 1. Indivudal numbers of each group.

Station No.	F 23						F 27		
Location Lat. N	34–28	34–27	34–24	33–59	34–29	34–32	34–25	33–59	34–05
Long. E	142–17	142–16	142–15	142–03	142–17	142–22	150–34	149–59	150–04
		↓	↓	↓	↓	↓		↓	↓
Lat. N		34–28	34–27	34–07	34–30	34–35		34–04	34–09
Long. E		142–17	142–16	142–12	142–20	142–22		150–04	150–06
Date	6–17	6–17	6–17	6–15	6–17	6–17 –18	6–24	6–23	6–23
Time	1040	0910	0630	1715	1130	2055	2300	0830	1125
	1110	1050	0840	2030	1515	0400	2345	1030	1430
Hauled Distance (m)	0–500	500–1000	1000–2000	2000–3000	3000–4000	5000–6500	0–500	1000–2000	2000–3000
Radioralia	+	+	–	–	–	–	+	–	–
Coelenterata	670	82	20	113	(1)	–	217	11	(4)
Chaetognatha (w)	1287	181	50	35	(18)	(10)	235	16	(1)
(c)	–	–	10	–	–	–	–	–	–
Nemertini	–	–	2	1	–	–	1	1	–
Polychaeta	106	12	3	–	–	–	4	–	–
Crustacea: Copepoda (l)	954	643	112	95	(3)	(4)	202	52	–
Crustacea: Copepoda (s)	3728	285	18	28	(122)	(88)	312	40	(11)
Crustacea: Ostracoda	631	65	11	14	–	(4)	88	2	(1)
Crustacea: Mysidacea	–	–	6	1	–	–	–	1	–
Crustacea: Euphausiacea	47	107	33	10	–	–	113	1	–
Crustacea: Amphipoda	154	101	6	12	(4)	–	16	2	–
Crustacea: Decapoda	–	13	1	13	–	–	7	15	–
Pteropoda	33	–	–	5	(2)	(10)	30	–	–
Ascidiacea	–	–	2	2	–	–	–	1	–
Thailiacea	641	2	2	36	–	(2)	148	–	–
Pisces	2	20	5	18	–	–	14	12	–
Pisces scale	–	100	6	8	–	–	124	5	–
Egg	18	–	–	4	–	–	8	–	–

(w), (c): Intestine is stained with orange oil grobules in (c) and not stained in (w).
(l): larger than 1.5 mm
(s): smaller than 1.5 mm

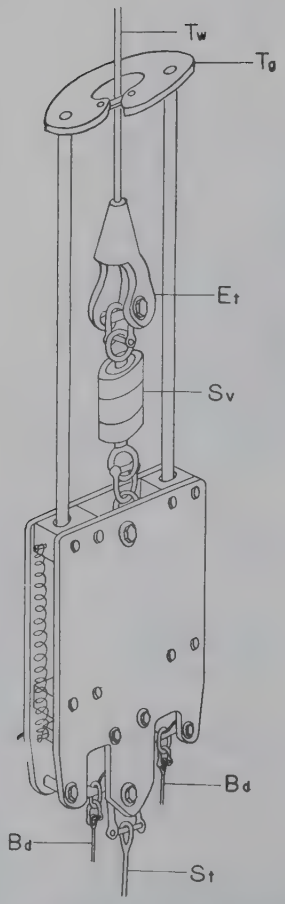

Fig. 2. Large-sized release. Abbreviation **Bd**; bridle, **Et**; end of tapered wire, **St**; trunk ring suspender, **Sv**; swivel, **Tg**; trigger, **Tw**; tapered wire.

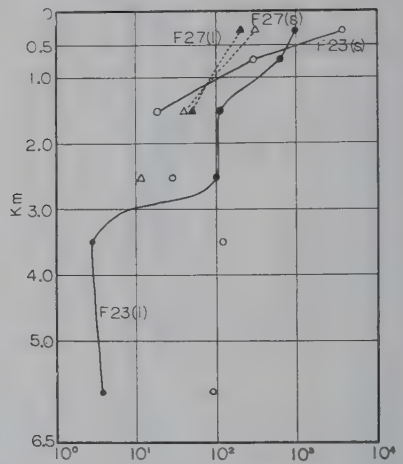

Fig. 3. The vertical distribution of the individual numbers of Copepoda at stations F23 and F27.
(l) Copepoda larger than 1.5 mm
(s) Copepoda smaller than 1.5 mm

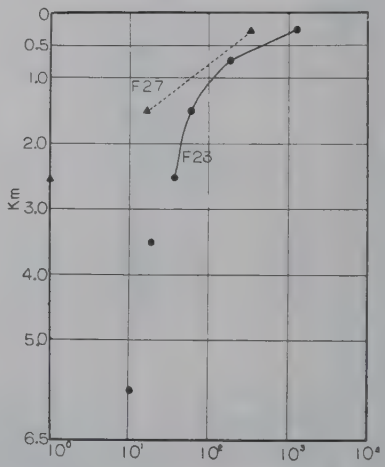

Fig. 4. The vertical distribution of the individual numbers of Chaetognatha at stations F23 and F27.

of the closing apparatus, bridles attached to the mouth ring were released and the net was hung from the apparatus by a trunk ring suspender as shown in Fig. 1-C.

Locations of sampling sations, dates and times of samplings, hauled layers were summarized in Table 1. Mid-water animals collected in each layer at each station were sorted into sixteen taxonomical groups, in the same manner as previous JEDS surveys. They were counted and tabulated in Table 1.

At a glance of the Table, we can judge it that copepods are most predominant animals in number among all groups and chaetognaths come to the next, while coelenterates, crustacean decapods and deep sea fishes are rather few but quitely conspicuous because of their larger sizes, brilliant colors and various shapes. Same results had been obtained through previous three JEDS surveys (Suyehiro et al., 1960; Matsue et al., 1961 and 1962; Marumo, 1961). But copepods are rather small in size compared with cases of JEDS-2 and 4, and chaetognaths with orange color oil grobules are very scarece, they are found only in the layer of 1000—2000 m at station F_{28}.

The vertical distribution of copepods and that of chaetognaths are presented in Fig. 3 and Fig. 4, respectively. It is obvious that in the layer deeper than 3000 m at station $F_{..}$ and in the layer deeper than 2000 m at station $F_{2.}$, quantities of mid-water animals suddenly decrease. Examining species of copepods and chaetognaths in these layers, they are all surface forms such as *Acartia negiligens*, *Acrocalanus* spp., *Calocalanus pavo*, *Clausocalanus* spp., *Corycaeus* spp., *Ctenocalanus vanus*, *Lucicutia flavicornis*, *Lubbockia* spp., *Mecynocera clausi*, *Oithona plumifera*, *Oncaea* spp., *Paracalanus aculeatus* etc. and *Pterosagitta draco*, *Sagitta bipunctata*, *S. serratodentata pacifica*, *S. serratodentata pseudoserratodentata* etc. As to chaetognaths, juveniles are large in number. So numbers of animals of these layers were parenthesized in Table 1. This may suggest that the scarcity of animals in the layer deeper than 3000 m station $F_{2.}$ and 2000 m station $F_{2.}$ is an undeniable fact. The upper filtering part of the net is made of coarse nylon cloth having 3.0 mm × 3.0 mm mesh apertures, so that the above-mentioned small surface forms may enter the net through coarse mesh apertures near the surface layer.

Quantitative comparison of animals between station $F_{..}$ and $F_{2.}$ gives the fact that standing crop of animals are more abundant in the rather near shore area F_{28} than in the high-sea area $F_{2.}$. Numbers of animals in layers of

0–500 m and 1000–2000 m at station F_{27} are equivalent to those in layers of 500–1000 m and 2000–3000 m at sation F_{23} respectively.

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Vol. 14. No. 2, March 1963

Heat Flow Measurement in the Western Pacific during the JEDS-5 and Other Cruises in 1962 aboard M/S Ryofu-Maru*

By

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Hideo AKAMATSU *Japan Meteorological Agency*

(Received February 20, 1963)

Terrestrial heat flow measurements were made at nine localities in the western Pacific during the cruises of M/S Ryofu-Maru in 1962. Together with our previous three measurements,[1)2)] there are now 12 heat flow values in the Pacific off Japanese Islands. The new heat flow stations are F 20, F 23, F 24 and F 25 of JEDS-5 (the Japanese Expedition of Deep-Sea, the fifth cruise), Akko 7, Akko 8 of 62-08 cruise, Akko 11, Akko 12 of 62-11 cruise of M/S Ryofu Maru, and MYJ 1. The last named station was taken about 20 miles northeast of Miyake-Jima Island when the Ryofu-Maru was sent to the Island on its volcanic eruption in August 1962.[3)] The results of the present work are summarized in Table 1. The stations and the heat flow values are shown in Fig. 1 together with simplified bathymetric contours.

The measurement of the thermal gradient in the sea bottom was made by means of the thermogradmeter developed by us.[4)] The thermal time constant of the probe was shortened, for the latter three stations, following the fashion used by von HERZEN et al.[5)]: the outer and inner diameters of the probe were 19 mm and 12 mm and the thermistors were pushed against the probe wall by a spring to ensure good thermal contact.

The thermal conductivity of sediments obtained at JEDS-5 stations were measured by the divided bar method back in the laboratory. The density and water content were also measured on these samples. Fig. 2 (a, b) shows the relationships between the observed thermal conductivity, density, and water content of

* JEDS Contribution No. 47

Table 1.

Station	Water depth (m)	Position co-ordinates		Thermal gradient (°C/100m)	Thermal conductivity (10^{-3} cal/cm sec°C)	Terrestrial heat flow (10^{-6} cal/cm² sec)
		Lat. (N)	Long. (E)			
E 1	1710	38 09	142 58	1.30	2.10	0.27
E 2	7345	37 59	143 58	5.42	2.11	1.14
E 6	5630	38 12	147 55	10.5	1.95	2.05
F20	5605	33 39	161 39	6.81	(2.00)†	(1.36)†
F23	7490	34 23	142 15	6.30	2.21	1.39
F24	5110	34 04	142 56	5.98	2.07	1.24
F25	5770	33 53	145 26	5.49	1.81	0.99
Akko 7	5480	39 22	150 03	17.39	1.90	3.30
Akko 8	2800	39 30	143 28	4.68～6.24	2.16	1.01～1.35
MYJ 1	1710	34 32	139 46	5.74	2.54	1.46
Akko 11	3960	29 53	137 56	3.97	2.06	0.82
Akko 12	3970	32 35	138 06	>12.0	2.42	>2.88

Remark: Measurements at Stations E1, E2, E6 are already reported[1)2)].

† Heat flow value at station F 20 is a tentative one, as no sediment was obtained.

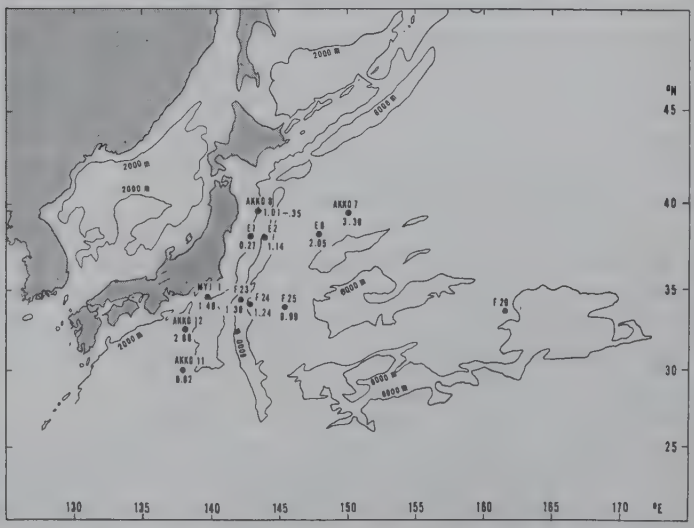


Fig. 1. Heat flow stations and heat flow values in the unit of 10^{-6} cal/cm² sec.

these core specimens. It seems that the relationship noted by others[6)7)] seems to hold in the sediments of the western Pacific too. The thermal conductivity

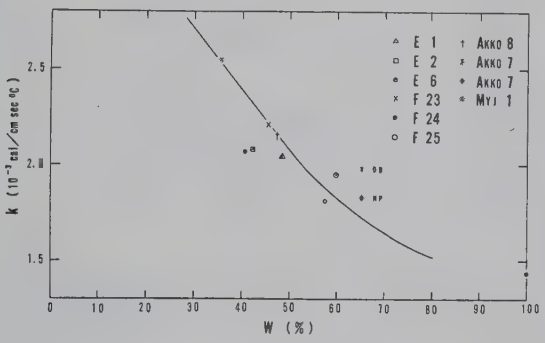


Fig. 2, a. Relation between mean thermal conductivity k and mean water content W of the sediment samples collected in each of heat flow stations. The curve showing approximate relation between k and W is taken from RATCLIFFE's paper.[8)]

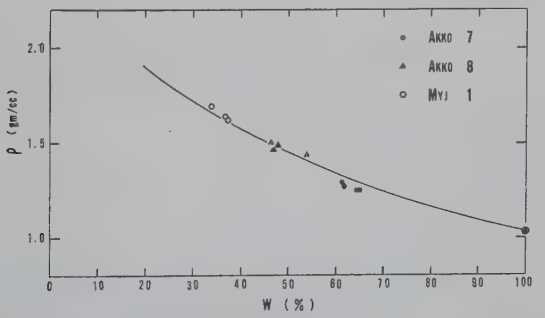


Fig. 2, b. Relation between bulk density ρ and water content W of the sediment samples collected at Stations Akko 7, Akko 8 and MYJ 1. The relation is approximately represented by the formula $1/\rho = W \cdot 1/\rho_w + (1+W) \cdot 1/\rho_s$, where $\rho_w = 1.03$ gm/cc and $\rho_s = 2.40$ gm/cc are bulk densities of sea water and sediment particles.

of sediments at stations Akko 8 and Akko 9 was measured both by the divided bar method and the transient method utilizing a thin needle probe. The latter method was developed by von HERZEN and MAXWELL[8)] and one of us (S. U.) constructed an apparatus for this method in cooperation with von HERZEN during

his stay at Scripps Institution of Oceanography in 1962. The temperature change ΔT of the probe is given to a good approximation by, for t large compared to a^2/κ,

$$\Delta T = \frac{q}{4\pi K} \log 4\kappa t/Ba^2,$$

where t = time,
q = heat input per unit length per unit time,
K = thermal conductivity of sediment sample,
κ = thermal diffusivity of sediment sample,
a = probe radius,
B = constant = 1.7811.

By taking the slope of the observed ΔT *vs.* $\log t$ curve, K can be obtained provided q is known. In practice, the slope can be conveniently obtained by the following formula, (von HERZEN):

$$K = \frac{q}{4\pi\Delta T} \log(t_2/t_1)$$

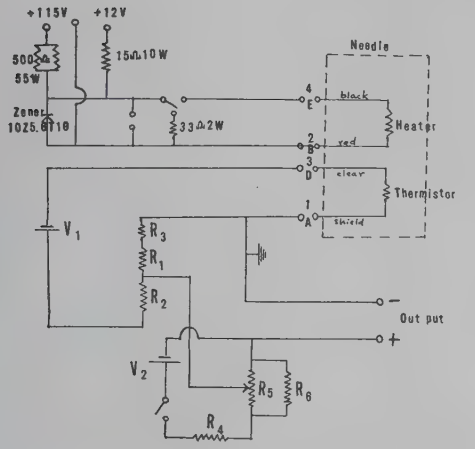
$$= \frac{q \cdot F}{4\pi\Delta E} \log(t_2/t_1) = \frac{q \cdot F}{4\pi\Delta E} \times 4.60,$$

where $$q = \frac{(\text{Heater voltage})^2 \times (0.2389)}{(\text{Heater resistance, } \Omega) \times (\text{Heater length})},$$

F = sensitivity of the apparatus, mv/°C,
ΔE = output voltage in mv,
t_2 = 420 sec,
t_1 = 10 sec.

Thus, a measurement finishes in seven minutes.

The outline of the apparatus is shown in Fig. 3. The temperature change in the sediment due to the heating effect of the heater in the hypodermic needle causes the resistance change of the thermistor (Veco Bead Thermistor No. 32 A 5, R (25°C) = 2~3 kΩ, R (0°C)/R(50°C) = 5.6) which is also in the needle. The resistance change of the thermistor is detected by the change in the output voltage over $R = R_1 + R_3$, and is recorded by an automatic millivolt recorder. A bias circuit is attached as shown in the figure so that the relatively high sensitivity (~8mv/°C) can be maintained in a wide range of the ambient temperature (10 ~40°C). Four probe needles were made whose characteristics are in Table 2 a. The approximate output voltages are listed for the four needles, with various setting of the bias resistance in the unit of 100 Ω are listed in Table 2 b. The



$R_1=800.4\,\Omega$ $R_4=1000.1\,\Omega$

$R_2=301.2\,''$ $R_5=996.3\,''$

$R_3=3.4\,''$ $R_6=36.61\,\Omega$

$R_1+R_2+R_3=1105.0\,\Omega$ $R_4+\dfrac{R_5\times R_6}{R_5+R_6}=1970\,\Omega$

$V_1=V_2=1.35$v

Fig. 3. Circuit diagram of needle probe thermal conductivity apparatus.

Table 2a. Needle characteristics.

Needle No.	1	2	3	4
Length (mm)	88	88	76	46
Diameter (mm)	1.2	1.2	1.2	0.86
Heater wire length (mm)	125×2	129×2	110×2	85×2
Heater resistance (Ω)	42.80	43.40	37.05	28.50
Heater voltage (V)	5.12	5.12	5.11	5.09
Line drop (−0.03 V)	5.09	5.09	5.08	5.06
q (heat) (cal/cm sec)	0.0116	0.0110	0.0151	0.0253

Table 2b. Approximate output (millivolts) of needles.

Temp.	Bias	Needle No. 1	No. 3	Bias	No. 2	No. 4
13°C	8.00	+50	+47	7.00	+58	+69
17	7.00	8	5	6.00	21	33
21	〃	33	31	〃	51	64
25	〃	60	59	〃	82	96
29	6.00	23	21	5.00	47	61
33	〃	52	51	〃	79	93
37	5.00	16	15	4.00	44	58
41	〃	46	46	〃	75	89
45	〃	74	78	3.00	39	53

Table 2c. Needle sensitivities (mV/°C).

Temp. Range	Needle No. 1	No. 3	No. 2	No. 4
18°~12°	6.05	6.04	7.23	7.44
21°~15°	6.25	6.42	7.40	7.68
24°~18°	6.50	6.72	7.64	7.81
27°~21°	6.86	6.90	7.80	7.86
30°~24°	7.13	7.18	7.85	7.86
33°~27°	7.28	7.36	7.84	7.86
36°~30°	7.39	7.46	7.85	7.87
39°~33°	7.45	7.64	7.82	7.86
42°~36°	7.40	7.80	7.66	7.65
45°~39°	7.28	7.96	7.58	7.55

apparatus is quite similar to those which had been in use at Scripps Institution of Oceanography, except that the circuitry is much simplified.

Choice of the resistance values R_1+R_3 and R_2 was made to obtain the best

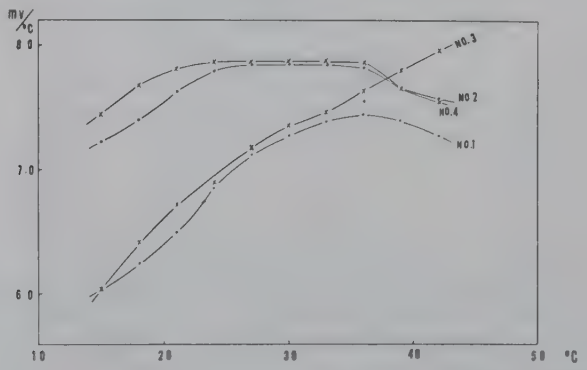


Fig. 4. Sensitivity of needle probes as dependent on the ambient temperature.

linearity of output voltage *vs.* temperature characteristics with the thermistors used. The relationship between the ambient temperature and the sensitivity is shown in Table 2c and Fig. 4. The trimming resistors R_4 and R_6 were used in order to make the resultant resistances equal to an ohm with those of the apparatus made for the Scripps Institution at the same time. This ensures that there will be no systematic differences in the work of the two institutions

Table 3

Distance from the top of the core (cm)	Water content (%)	Thermal conductivity (10^{-3} cal/cm sec°C)	Method
Station AKKO 8 (39°30′ N 143°28′ E)			
80– 85	46.6	2.16	D.B
85– 95		2.20	N.P
100–105	47.3	2.15	D.B
105–115		2.18	N.P
120–125	49.7	2.06	D.B
125–135		2.09	N.P
140–145	45.7	2.22	D.B
Station AKKO 7 (39°22′ N 150°03′ E)			
10– 15	66.2	1.87	D.B
15– 20		1.80	N.P
25– 30	66.3	1.92	D.B
35– 40		1.83	N.P
40– 45	63.7	2.07	D.B
55– 60	63.6	2.07	D.B
60– 70		1.85	N.P

in the future. The results of the measurements on the sediments of stations Akko 8 and 9 by both methods, indicated a good agreement as shown in Table 3. The slight difference may be either indication of the error or the real difference due to the fact that slightly different parts of a core specimen were measured. On account of the good agreement mentioned above, thermal conductivity measurement of the sediments of stations Akko 11 and 12 was made only by the needle probe method aboard the ship.

The number of heat flow measurements at sea is still quite small and the stations are too sparse to draw any conclusion regarding the geographical distribution. A few things to be noted may be: a. The stations placed at the axial deep of Japan Trench showed rather normal heat flow, i. e. 1.14×10^{-6} cal/cm² sec at E 2[illegible] and 1.39×10^{-6} cal cm² sec at F 23. b. The western Pacific basin may have a region of high heat flow as indicated by the values at two stations E6 and Akko 7. More stations are necessary before establishing both the existence and the regional extent of such a region. c. Station MYJ 1, which was taken some 20 miles northeast of a then erupting volcanic island, volcano Miyake-jima, showed normal heat flow 1.46×10^{-6} cal cm² sec. The station was situated in the outer side of the Izu-Mariand Volcanic arc. It is highly desirable, in relation to the results of the land measurements,* to make measure-

Table 4.

Station	Date	Lat. (N)	Long. (E)	Depth (m)	Time at surface (h,m)	Time of bottom contact (h,m)	Duration in bottom (min)	Time at surface (h,m)	Wire length at bottom contact (m)	Apparatus
F20 (Akko 1)	May 23	33°39′	161°39′	5605	10 38	13 20	19	18 30	5880	R1
F23 (Akko 2)	June 16 –17	34 23	142 15	7490	19 23	23 48	56	06 00	7860	R1
F24 (Akko 3)	June 19	34 04	142 56	5110	02 25	05 01	78	10 15	5220	R1
F25 (Akko 4)	June 27	33 53	145 26	5790	18 34	21 37	62	02 45	5900	R1
Akko 5	June 12	33 45	140 30	890	17 45	18 20	120			R2
Akko 6	Aug. 15	39 30	149 59	5491	09 55	12 51		17 30	5490	R1
Akko 7	Aug. 16	39 22	150 05	5480	20 10	22 40	60	03 20	5580	R1
Akko 8	Aug. 22	39 29.5	143 28	2800	19 10	19 55	105	22 40		R1
MYJ 1a (Akko 9)	Sept. 30	34 32	139 46	1710		10 00				R1
MYJ 1 (Akko10)	Sept. 30	34 32	147 56	1710		14 51	24			R1
Akko 11	Nov. 11	29 53	137 56	3960	16 00	18 01	17	20 45	4820	R1
Akko 12	Nov. 12	32 35	138 06	3970	16 40	20 37	38	23 25	4070	R1

Remarks:

Station F20 (Akko 1) .....Successful. No sediment sample was taken.

Station F23 (Akko 2) .....Successful.

Station F24 (Akko 3) .....Successful. Probe bent sharp at the middle part, indicating partial penetration. Thermograd record supports partial penetration.

Station F25 (Akko 4) .....Successful. Thermograd record indicates partial penetration and only the temperature difference $\alpha-\beta$[4] was used.

Station Akko 5 .....Unsuccessful. Thin-probes broke. Junction of the core barrels, to which thin probes were attached also broke.

Station Akko 6 .....Unsuccessful. Zero line of the thermograd record was not recorded.

Station Akko 7 .....Successful. Partial penetration.

Station Akko 8 .....Successful.

Station MYJ 1a (Akko 9) .....Unsuccessful. Probe pulled out as soon as its bottom contact.

Station MYJ 1 (Akko 10) .....Successful. Partial penetration. Bottom sediment has small water content (about 36%) and high thermal conductivity.

Station Akko 11.....Successful. Small heat of penetration, Probe bent in a complex way.

Station Akko 12.. .....Successful. Large heat of penetration. Partial penetration is indicated on the thermograd record. Greysh white sediment core with high viscosity was obtained. The thermal conductivity is high.

ments in the inner area of the arc: the land measurements have indicated that the outer side of the Japan arc proper is a region of low heat flow and the inner side is a region of high beat flow and Cenozoic volcanism.

During the cruises in 1963, 11 trials of heat flow measurements were made. As noted above, 9 of these were successful. One unsuccessful trial was made with a thin-probe method similar to the one used by GERARD, LANGSETH and EWING[10]: all the thin probes attached to the piston corer broke. Because of its obvious advantage that only a minute or two will be sufficient for attaining a steady state in the sediment, the thin probe-method will be studied more in future work.

Another failure was made near station MYJ 1: this time the glass ball breaker did not work well and the probe did not contact the bottom. Use of soner pinger for tracking the probe will be helpful in avoiding this kind of failure. At station F 20, no sediment core was taken, so that the conductivity was assumed to be 2.00×10^{-3} cal/cm sec°C.

Some details of each station are listed in Table 4.

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